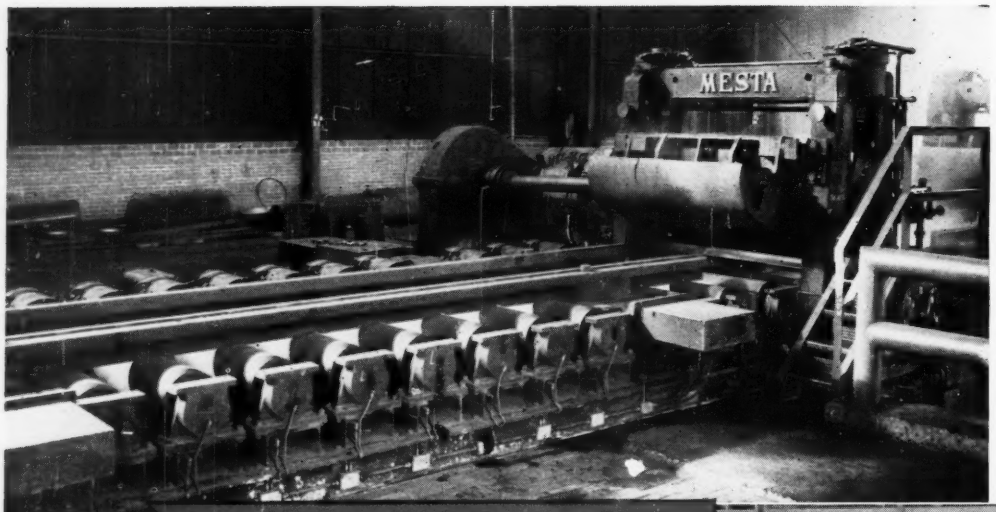
Practical Feature: OPEN GEAR LUBRICATION
1953 Subject & Author Indexes

DECEMBER, 1953
Vol. 9, No. 6

Lubrication ENGINEERING

GEAR TOOTH STRESSES

JOURNAL OF
THE AMERICAN SOCIETY OF LUBRICATION ENGINEERS



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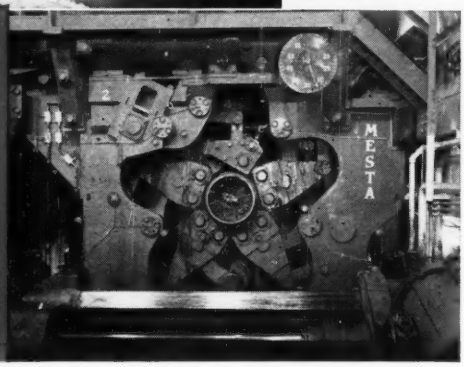

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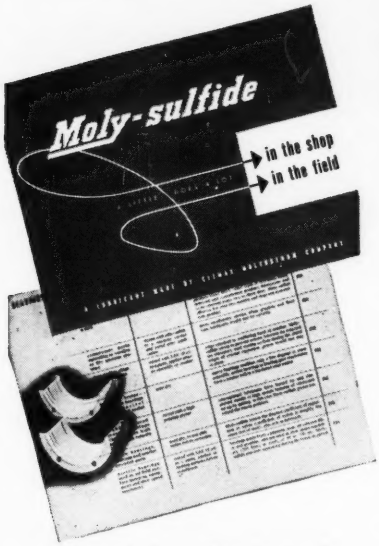

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Lubrication ENGINEERING

December, 1953, Vol. 9, No. 6

TABLE OF CONTENTS

Air Bearings—Low Friction
by D. D. Fuller 298

Critical Rake Angle Method of Evaluating Cutting Fluids, The
by W. E. Lauterbach & E. A. Ratzel 313

Electrographic Spot Testing of Bearing Surfaces
by A. E. Roach & A. O. DeHart 302

Foil Bearing—A New Departure In Hydrodynamic Lubrication, The
by H. Blok & J. J. vanRossum 316

Mechanisms Of Sleeve Bearing Failure
by P. B. Burgess 309

Open Gear Lubrication (Practical Lubrication, No. 10)
by H. W. Winkler 294

Units Of Viscosity And Their Conversion
by D. D. Fuller & P. L. Tea, Jr. 307

Advertisers' Index 336
Annual Meeting Hi-Lites 292
Board Actions 329
Book Reviews 324
Current Literature 330
Directory, ASLE 322
Industrial Members, ASLE 324
Lube Lines 293
Lubrication in the News 312
Membership Classifications, ASLE 333
Patent Abstracts 325
Personals 312
Section News 301
Subject & Author Indexes 321

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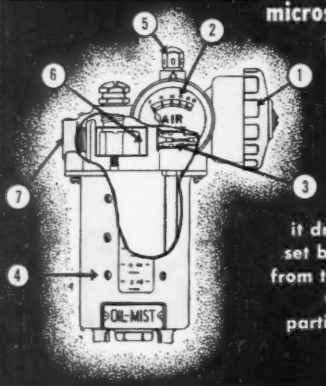

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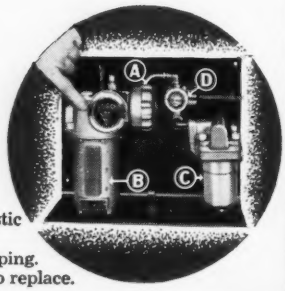

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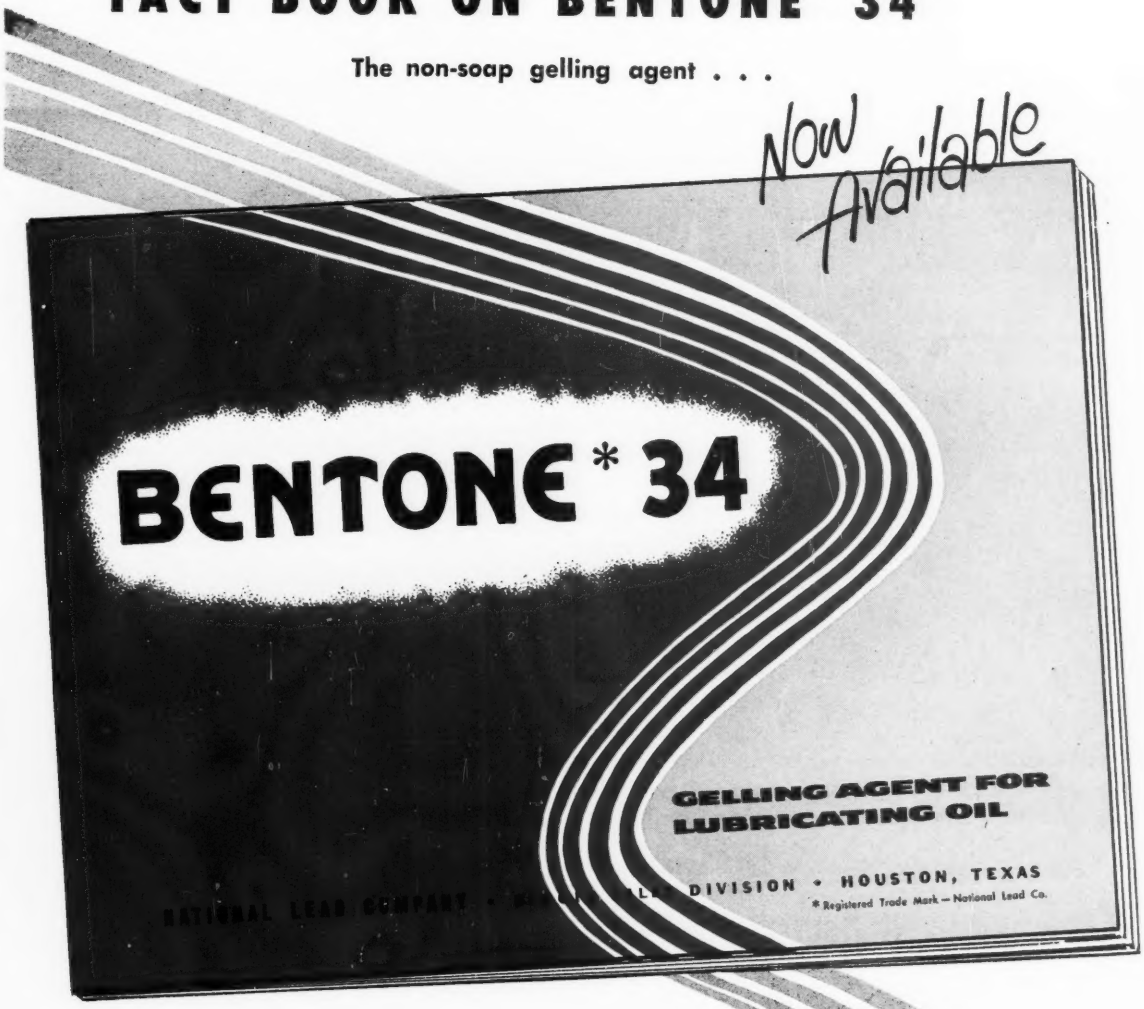
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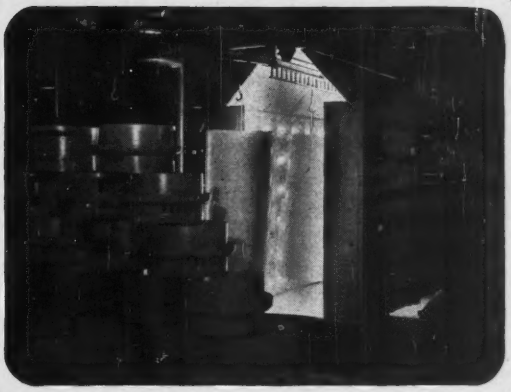

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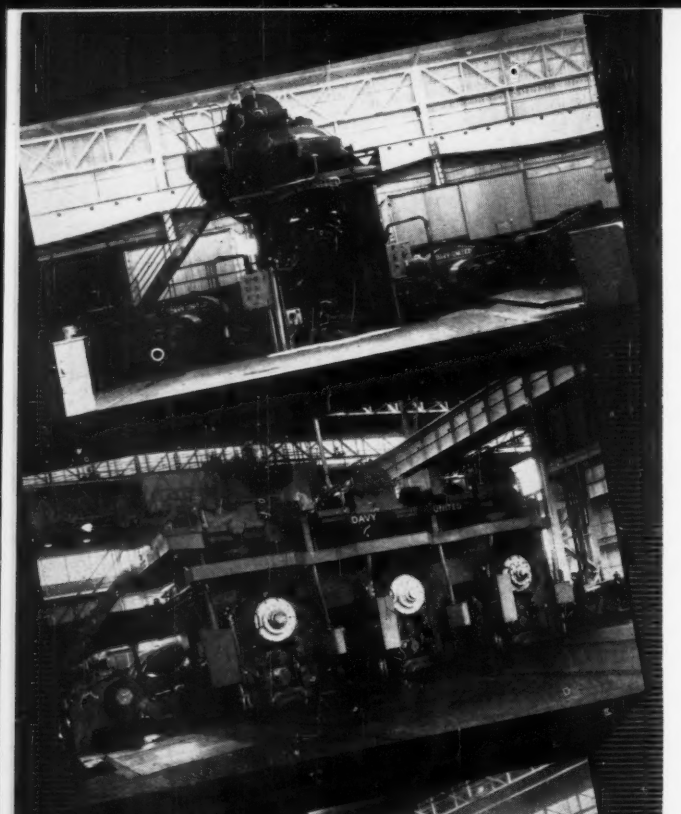

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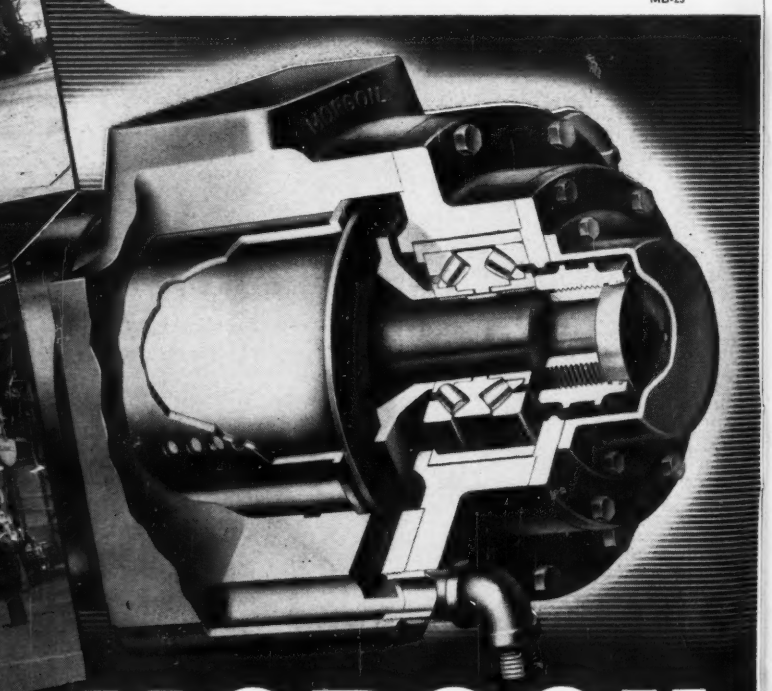

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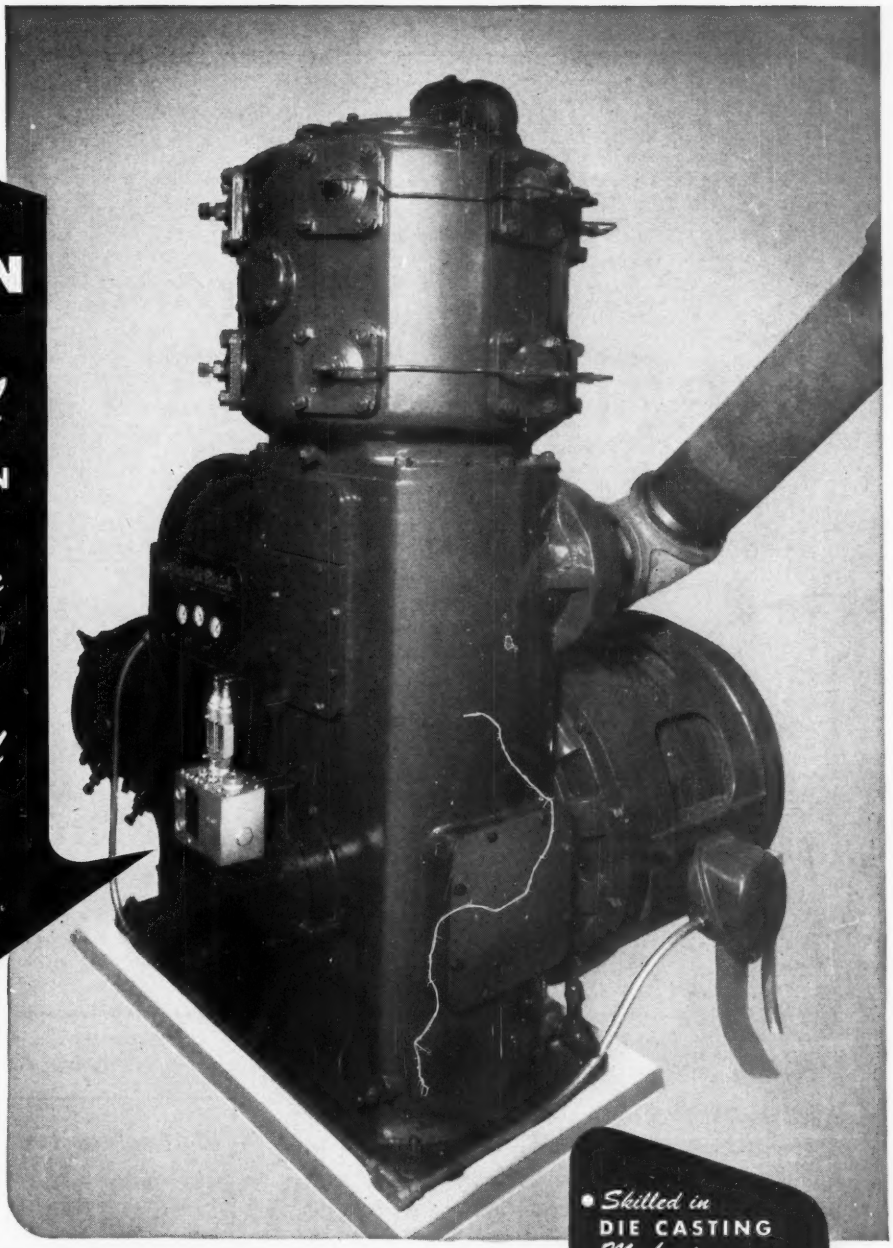

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- Bearing Design Today
- Behavior Of Sleeve Bearing Materials, by C. M. Allen & K. A. Davis
- Boundary Friction Of Very Well Lubricated Surfaces, by E. Rabinowicz
- Fleet Taxi Engine Wear, by O. Wuerz
- Frictional Properties Of Soap At High Pressures, by J. R. White
- How To Put Across A Technical Paper Or Report, by L. N. Rowley
- Lubrication Application Problems & Their Solution In The Coal Industry (Panel)
- Lubrication Application Problems & Their Solution In The Steel Industry (Panel)
- Metalworking Session, covering wire drawing, wax lubrication & metal-cutting cutting oils
- Micro Testing Of Greases, by H. V. Wadlow & E. E. Campbell
- Railroad Bearing Lubrication
- Reclamation Of Industrial Petroleum Products (Symposium)
- Rust Prevention, by E. J. Schwoegler
- Surface Active Preventives In Lubricating Oil, by D. W. Criddle
- Synthetic Lubricant Clinic

NEW LUBRICATION COURSE TO ACCOMPANY ANNUAL MEETING: The ABC's of Lubrication Engineering, five 3-hour class sessions covering the basic principles of Lubrication Engineering and presented by leading experts in the field, will be offered plant personnel starting Monday afternoon and continuing the morning and afternoon of the following two days. Registrants will be able to attend the regular meeting sessions and exhibits when time permits.

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A NEW ASLE PUBLICATION: When a ball or roller bearing becomes damaged in service, proper diagnosis of the cause of damage is the key to correcting the difficulty and preventing a repetition of the trouble. INTERPRETING SERVICE DAMAGE IN ROLLING TYPE BEARINGS—A Manual On Ball & Roller Bearing Damage, a new 32 page booklet based upon papers presented before the 1953 Annual Meeting of the Society is now available, which includes drawings, tables, and 74 photographs for aiding in the classification and identification of the causes of many of the common types of bearing damage. Price $1.00. (Write ASLE Publications, 84 E. Randolph St., Chicago 1, Ill.)

SELLING ENTHUSIASM FOR PLANNED LUBRICATION: Practical lubrication is a lot of things, not all of which are technical, and it is revealing to note that many universities teaching this subject include psychology in the curriculum. They recognize that it is useless to know how a machine or process should be lubricated unless both management and operators are in full agreement. The necessity of winning over management to a planned lubrication program is obvious; they must underwrite it before it can be put into effect, but too often the necessity of convincing operators is overlooked. Their enthusiastic co-operation is essential to a successful lubrication program while their indifference spells early failure. Lubrication is not a one-shot job to be performed and forgotten. It is a continuing effort which requires meticulous and constant attention to details. The necessity of continued care is not too obvious at the working level and the lubrication engineer would do well to develop convincing facts and figures and to share the full story with all concerned. S.K.T.

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FARRINGTON-AISE FUND ESTABLISHED: At a recent meeting the board of directors of the Association of Iron & Steel Engineers voted to give Rose Polytechnic Institute at Terre Haute, Ind., the sum of $1,500 which will be known as the Farrington-AISE Fund and used by the school for scholarships for needy engineering students of high standing or will be used for the purchase of equipment needed by the school. This award was established as a tribute to James Farrington, founder and first president of the AISE; Mr. Farrington, who is still active in the steel industry, was one of the pioneers in the electrification of the steel industry and in the application of electric drives and control for steel plant operations. His contributions and those of the organization which he founded have been an important factor in making the steel plants a better place to work and in enabling production of better steel at more economical costs.

RESEARCH INFORMATION SERVICE: For more than half a century the John Crerar Library, 86 E. Randolph St., Chicago, has been collecting the results of research in science, technology, and medicine, in every language and from every country of the world, until today it is the largest library in the United States, perhaps in the world, devoted exclusively to these scientific fields — its resources now include approximately one million volumes and pamphlets and current subscriptions to thousands of technical and scientific publications of a periodical nature. All of the library's collections are available for use without charge by anyone interested. Through Interlibrary Loan, books or periodicals are sent to other libraries anywhere in the United States, and a complete microfilm and photostat service quickly reproduces material needed for use outside the library.

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(Continued on page 320)

Practical Lubrication, No. 10

OPEN GEAR LUBRICATION*

by H. W. Winkler
The Brooks Oil Co.
934 Ridge Ave., NS
Pittsburgh 12, Pa.

The lubrication of open gears has for many years had the attention of maintenance men, lubrication engineers, and those engaged in the manufacture and sale of lubricants. More recently much study has been given to the application of lubricants to open gears, and there have been several articles published on this phase which cover the field carefully. It is the object of this paper to cover the physical and chemical characteristics of the products which have been and are being used on open gears.

There are many cases where the lubrication of an open gear is a simple matter. Instances are known of gears which have been in service for years. It would be possible to point out specific cases where gears have been in service longer than some of us have lived. This is partially a credit to the gear manufacturer or to the person responsible for the design of the equipment. However, under modern conditions it is increasingly apparent that the proper lubricant is also somewhat responsible for long gear life. Much could be said about the early types of lubricants, but present ideas derive from the advent of petroleum lubricating oils.

Shortly after crude petroleum came into commercial use, a type of gear grease was developed that was manufactured by treating rosin with lime, plus the addition of petroleum lubricating stocks. This type of gear grease has served industry well. It is the kind of product which can be applied with a paddle, a method that is very acceptable for hand application. This grease, once it is applied, will soften in consistency and spread over the face of the gear. It has a limited amount of drying action which is desirable. Rosin soap grease has a fair degree of resistance to the washing action of water. The biggest disadvantage in the use of this product is that it has a low melting point, and in service it continues to increase in fluidity. Rosin soap base gear grease is still used, and on many industrial gears it is difficult to replace.

Perhaps one of the reasons the use of rosin gear grease has decreased is that it does not lend itself to modern pressure application. As a rule it is not uniform in texture and hence is not suitable for the precision mechanism associated with pressure systems.

Other early open gear lubricants were petroleum black oils, cylinder stocks, and petrolatums, altho there is evidence which indicates that petroleum oils with calcium resinates, as well as pine oils and pitch were used before this. The former products are still in use, but to a large extent have given-way to prepared gear greases and compounds.

The next development in the lubrication of open gears, with products which were basically petroleum was the use of calcium soap base grease manufactured from animal and vegetable fats. This type of lubricant can be likened to cup grease, but it is made with heavier oil. It offers good resistance against agitation and can, therefore, be supplied in more fluid consistencies. Calcium soap grease can be adjusted to all of the usual ways of applying grease to open gears. It also has the advantage of being resistant to the washing action of water. This grease in general is not suitable for applications where operating temperatures are much above 100 F., since the loss of moisture contained in the grease destroys the normal texture. It has the advantage of remaining more plastic when temperatures are lowered, and this makes for ease of handling during cold weather. Grease of this kind is low in film strength and has a tendency to wipe off. In general its adhesive quality is governed by the petroleum oil used in the product.

In the lubrication of open gears, extensive use of the fibrous sodium soap base grease has been made. This lubricant can be made in fluid consistencies and has a stringy or fibrous texture, which in many instances aids in its application to the moving gear. Sodium grease can be manufactured in various grades from a firm block grease to a very fluid lubricant. This grease can be adjusted to meet all forms of application. Sodium soap grease also has the advantage of being stable to heat. A disadvantage is its solubility in water, which eventually destroys the consistency and lubricating value.

Aluminum soap base grease as used on open gears is usually manufactured to have a stringy texture, which aids in coating the gears. It also has good resistance to the washing action of water. Straight aluminum soap base grease does not function well where there are high temperature conditions. It does lend itself to pressure system applications because it can be made very uniform or homogeneous, and as a general rule is easily applied even at low temperatures.

The four different types of gear grease thus far mentioned, the rosin base, calcium soap, soda soap, and aluminum soap lubricants are suitable for gear lubrication where conditions are what might be termed normal, such as moderate temperatures, and low pressure per square inch on the rubbing surfaces of the gear teeth.

The primary use of these soaps in grease is to impart body or consistency. They have limited value as lubricants and their chief function is to assist in applying to the gear the petroleum lubricating

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oil and any other material which has been mixed into the soap.

There are a few metal soaps that are used in open gear lubricants which do not contribute much to their consistency or hardness. Of these, lead soap is outstanding. The type of lead soap most commonly incorporated is used to improve the lubricating value of the finished product. Lead soap assists in the wetting or covering action, and increases the film adhesiveness and film strength. It retards or prevents corrosion and assists in supplying a film which will lubricate in the presence of water. Lead soap film remains on idle gears, thus contributing to the initial movement when operation is resumed. This film is retained for long periods of time and thereby aids in corrosion prevention. Lead soap has a penetrating action on the surface of metal, thus providing total surface coverage and assisting in preventing scuffing, scoring or galling.

A limited quantity of gear grease is built around a few metal soaps other than those mentioned. Of these, zinc soap is used the most. It aids in surface coverage and film strength. Zinc soap is frequently used with zinc oxide and this combination offers increased lubricating value.

Greases made with barium and lithium soaps have limited application to open gears, and to date these lubricants have not been used extensively. There are indications that lithium soap offers good possibilities as a base for open gear grease.

Some assistance is obtained in open gear lubrication by using such bodying agents as the bentones or aerogels. These products when incorporated into lubricating oil help to hold the oil and maintain body or consistency in the presence of high ambient temperatures. The lubricating value of such compounds is relatively low, but they do offer a convenient means of obtaining partial relief against heat.

In recent years transmission of power by open gears has resulted in greater loads and higher speeds, due to the use in many instances of smaller gears. Today, for example, a gear three feet in diameter is used where possibly a six foot gear would have been used some years ago. This change in the size, design, and speed of gears has brought about a demand for gear lubricants which will meet these more severe conditions. For this purpose viscous types of either refined or residual petroleum stocks, frequently referred to as gear shield lubricants, have been developed. These products have good adhesive characteristics, and in addition possess fair fluidity. Into them can be built extreme pressure characteristics and lasting film properties.

Modern open gear lubrication is a field where the film strength of the lubricant is very important. In defining an open gear lubricant, this characteristic is frequently treated as if it were of little value. In actual service a product which has high E.P. characteristics combined with a lasting thin film will give the best lubrication with a minimum of power consumption. In this connection it is important to remember that most of the significant properties of a grease cannot be determined by visual inspection alone since similarities in appearance can often be misleading. These can only be fairly evaluated by laboratory tests and by final reference to operating performance.

In an effort to correlate laboratory evaluation of load carrying capacity with actual service, a modified test on the Timken Lubricant Tester has been of assistance. The standard Timken test procedure is to provide an ample flow of lubricant to the rotating cup. This method demonstrates film strength, but not endurance. The lasting value of the film can be studied by conducting the usual Timken test and at the end of the 10 minute period shutting-off the flow of lubricant. The length of time the film supports the load before scoring occurs helps to evaluate its durability. The minimum lever arm load for open gear lubricants should be at least 33 lbs., though weights of 43 and 53 lbs. are also used.

For lubricants which are not easily circulated in the Timken tester, a convenient method of studying the film is to coat the cup and block with 4 grams, approximately one level teaspoonful of the product, and run the machine until the film ruptures. A constant load is maintained, such as 43 lbs., and no additional lubricant is added. A run of 15, 30 or 45 minutes helps to evaluate the load carrying capacity.

These petroleum residual gear lubricants vary in viscosity from 250 to 10,000 seconds at 210 F., Saybolt Universal. The heavier grades have only slight fluidity at 75 F., hence must be heated for ease of application.

The manufacturer of lubricants, realizing that greases and compounds for open gears must of necessity be of heavy consistency to provide film thickness without dripping, have endeavored to assist in the application of lubricants by providing products which have a fair degree of fluidity at the time of application. The most popular approach to this phase of gear lubrication has been by the use of solvent. The basic principal involved is very similar to the use of turpentine in paint, with the exception that when the solvent has evaporated, a plastic film remains. There is also evidence that in addition to the ease of application, solvents assist in making a close bond between the lubricant and the face of the gear. The use of solvent has an additional advantage, in that a much heavier and more viscous lubricant can be applied. It is interesting to note that a material containing solvent requires less pressure for application than a similar bodied product which does not contain the solvent. As an illustration, a viscous gear lubricant with a viscosity of 6000 seconds at 210 F., S.S.U. can be reduced with a small amount of solvent so that the viscosity will be 1000 at 210 F. When this product is compared with a similar lubricant which contains no solvent, but which has a viscosity of 1000 at 210 F., it will be found that at lower temperatures the solvent type lubricant will require less pressure for movement in a system than will the straight product. By proper selection, it is possible to keep the amount of solvent at a rather small percentage. The purchaser of a solvent type gear lubricant should give consideration to the amount of solvent placed in the product. It is not difficult to understand that a gear lubricant with 10% or less of solvent offers the consumer much more in actual lubrication for his money than does a compound containing 30 to 40% solvent. The amount of solvent also in some instances presents a problem as to whether the fumes would be sufficient to be toxic, or in a quantity that may involve a fire hazard. Since most solvents used in petroleum lubricants are basically toxic and in most instances present a fire hazard, we arrive at the gen-

eral conclusion that the less solvent used the better the product.

This solvent type gear grease may be applied in many ways. It can be put on with a paddle, but also lends itself to brushing, swabbing, dripping, dipping, and splashing. In addition, it is convenient for spray application.

Solvent cut lubricant also enables the person responsible for lubrication to adopt methods for application that will be most economical and best suited for a particular job, and only one lubricant need be purchased.

In the consideration of open gear lubricants, attention should be given to the many conditions under which the gear operates. The viscosity or consistency of gear lubricants is perhaps a more important point than is frequently realized by those selling the product as well as those responsible for its use. Where the transmitted pressures are high or there are shock loads, then one must consider the use of extreme pressure lubricants. Regardless of conditions, lubricants should not cause any buildup on the working surface of the gear. An open gear lubricant should provide a film which adheres to the rubbing surface, covers the working area, and which will have sufficient strength to prevent metal to metal contact. It is frequently true that the surfaces of gear teeth are not too smooth, and that the actual area of contact is much less than is apparent from the rubbing or sliding surfaces. It is a common conception, therefore, that if the lubricant contained solid material the latter substances would fill the minute voids and thus bring about greater areas of contact. This idea for a gear compound usually involves the use of graphite, molybdenum disulphide, metal oxide, mica, powdered metal and talc. The indiscriminate use of these solid materials can lead to trouble unless the user is aware of the factors involved. Therefore some discussion of them will be appropriate here, while at the same time any intent to detract from their properly applied properties is specifically disclaimed.

It should be borne in mind that the vast majority of lubricating oils and greases have specific gravities lower than water, while graphite has twice that of water and most of the others are still higher. Graphite, due to its plate-like structure, has a tendency to slip or move in any oil in which it is suspended, and hence this results in separation. Graphite in almost any form, when used in a gear lubricant, should be less than 4% of the volume of the product. Less than 1% is perhaps even better. There are many grades of graphite with respect to texture, hardness, and purity, and its proper use, therefore, involves a field of study by itself.

To be sure, all of the products mentioned have perhaps at sometime aided temporarily in open gear lubrication, but it must not be assumed that if one of these products was helpful in a particular instance that it would be satisfactory under all conditions. If it is necessary to supplement lubrication with one of these solids then it should be used intermittently.

Perhaps the best way to use colloidal graphite or molybdenum disulphide is to apply it directly to a new gear or used gear which has been thoroughly cleaned. These aids can be applied dry or better suspended in a quick drying solvent using a brush or spray.

Viewing the problem of open gears purely as one of fluid film lubrication, it seems that it would be best to obtain gear protection by the use of a product which in reality contains no solids when in service. A lubricant composed of a homogeneous fluid and which would present a tough elastic film would be best. A film that is not ruptured by high pressure will provide against metal to metal contact, and also tend to increase the rubbing or sliding area. Produts of this latter type reduce the risk of abrasion and build-up. Gear failure may be attributed to the lubricant, but there are cases where metal fatigue and metal flow may take place without rupture of the lubricating film.

Much of the trouble experienced in the application of a lubricant can be overcome if attention is given to the temperature at the time of application. It has been well established that much time can be saved by proper handling of the product.

It can be generally assumed that the more difficult a product is to apply through any type of pressure system, the more difficult it is to squeeze or force out, while in service.

Unfortunately, open gear lubricants as a group, follow no general pattern with regard to fluidity and consistency. There is no standard test procedure which can be used on all products, since the various methods in use are limited in their scope. Hence it is difficult to predict how a pressure system will handle a material.

If it is necessary to apply a product heavy in consistency, then the equipment must be designed for the proper flow of the lubricant. If it is desired to use a material which has adhesive qualities and possibly cohesive properties, then you must bear in mind that such a lubricant will adhere to the tubing, valve, gun, or any device used to convey the product.

In the use of open gears, we have problems similar to those applying to many other phases of lubrication. Most of these problems must be treated as individual cases. The conditions under which the product must be used with reference to temperature, contamination, and means of application must be considered. If a heavy viscous or grease like lubricant is used, it is evident that it should not be stored where the product would be subjected to low temperatures. Many products such as greases, lubricating compounds, waxes, petrolatums, and fats, do not become fluid at the same temperature at which they solidify, and as a class they are poor conductors of heat. A drum of grease, once it has been cooled below its channel point, must be exposed to warm conditions for a long period of time before the lubricant will appear normal at 77 F., the temperature at which the consistency is usually judged. In all probability the product will have to be heated above 77 F., agitated slightly and then cooled, to determine its normal texture at 77 F. A safe rule to follow when heating lubricants, and other petroleum products, is never to apply direct heat. The source of heat should be uniform and less than 300 F., and the practice should be one of using more time and less heat.

If a lubricant is cold and consequently thick and viscous, the usual procedure is to apply sufficient heat to warm the product in the shortest possible time. This treatment can result in carbonization of the inside walls of the container holding the lubricant or on the heating element, if inserted in the product. The surface temperature of a steam heat-

ing coil or an electric heating element should be known before placing it in an oil or grease.

Heat applied to heavy, viscous materials does not readily create convection currents, hence excessive localized heating is probable. If possible, when a lubricant is heated, mechanical agitation should be provided. Most petroleum base greases and compounds are what might be termed semi-finished and are not stable under all conditions. Many important characteristics of lubricants are due to this semi-finished condition. The method of manufacture of many lubricants determines the qualities of the finished product. It is possible to use the same ingredients in the manufacture of a lubricant and by two different procedures in the same type mixer, obtain greases which do not resemble each other. The physical and chemical properties of many lubricants are the result of the manufacturing method. Hence in service these products may change, due to heat, age, pressure, contamination and other conditions.

In considering greases from the angle of consistency or behavior at the temperature of application, attention should also be given to external heat which may cause the gear to operate at a high temperature. To avoid trouble, a conservative rule to follow is to remember that compounds composed largely of petroleum oils, as mentioned before, should not be subjected to temperatures above 300 F. Even at this figure there are many applications which must be closely watched and all lubricant removed at frequent intervals. If petroleum oil is used as a conveyor of solids, a further reason for cleaning the gears at regular intervals is apparent. It appears that in addition to careful maintenance with regards to the lubricant, it is advisable, if possible, to provide suitable mechanical equipment which will aid in controlling the operating temperatures.

Much progress has been made in spraying lubricants on open gears. Centralized lubricating systems have been developed which handle gear lubricants effectively and have many economic advantages. In a system of this kind, the consistency-temperature relationship of the lubricant is an important factor since it governs the effectiveness with which the material can be pumped and sprayed. The actual application is dependent upon nozzle design and the distance the lubricant must travel to reach the gears. Any type of spray system must be tailored to the available air pressure. All portions of a pressure system, be it a single gun or one with many outlets, must be large enough so that the desired quantity of lubricant will flow with the available amount of pressure. When spraying lubricants of fairly heavy consistency and good adhesive properties, the problem of nozzle drip is sometimes annoying. This can be controlled by a system which prorates the amount of air to the amount of lubricant. The flow of air precedes the lubricant and continues after the lubricant is cut off.

While on the subject, it is well to mention that tubing containing copper is not desirable for grease in general, especially if the lubricant remains in the copper or brass sections for a period of time and if subjected to relatively high temperatures. Many designers of equipment for the application of lubricants are trying to avoid the use of copper and brass.

There are applications where a lubrication system should serve both gears and bearings. Progress is being made in adapting lubricants to such a system. It may be necessary to compromise, but if careful consideration is given to all the factors, it appears possible in many instances to find a solution to a problem of this kind.

An important problem in open gear lubrication is that of contamination of the lubricant with dust, dirt or particles of the materials which are being processed. This condition is frequently partially controlled by the use of a compound which provides a non-tacky and semi-hard finish. Dust or foreign solids do not adhere to such surfaces as readily as they do to the soft texture of many greases. Situations of this kind can also be partially controlled by the amount of lubricant which is on the gear teeth.

Another approach to this problem is apparent in a trend by lubrication engineers and maintenance departments, toward protecting open gears from surrounding dust and dirt by mechanical means. Such measures might be considered as needlessly expensive, but it is well established that mechanical installations that will eliminate contamination of the lubricant on open gears return their cost many times over, in lowering gear wear and consequent replacement. Such protection reduces the cost of labor in applying a lubricant and lengthens the life of both the lubricant and the gear.

To illustrate this, in a mill where contamination of open gear lubricants was a serious problem, the gears were protected with a sheet metal housing into which clean compressed air was blown. This created an outward flow of air and kept the gears from being contaminated by the surrounding dust. Washing gears with clean water is possible, if a lubricant is used that functions in the presence of water and has a density greater than water. Other methods of retarding contamination are possible, and it is evident that many of them aid greatly in more economical lubrication.

There appears to be a tendency among purchasers of open gear lubricants to demand that the material be low in cost as was formerly the case. Viewing the subject in the light of present day costs, it appears logical to keep in mind that gears cost more today and are frequently difficult to obtain. Obviously, better lubricants will be more economical in the long run but such products will naturally be higher in price. Lubricant manufacturers, like all types of industry, have increased the efficiency of manufacture, but today there are many other factors which enter into the cost of any manufactured product. Hence the price of lubricants has increased due to conditions beyond the control of lubricant manufacturers. The consumer of open gear lubricants should likewise remember that the manufacture of improved products will assist him in reducing his total cost of lubrication, therefore the initial cost per pound of an open gear lubricant is not the deciding factor, but rather what is the total cost of operating the open gears.

It has been our experience, that open gear life in industry has been increased many fold, especially where pressures are high with a consequent drop in gear replacement cost, by the intelligent application of modern gear shield type lubricants. This is particularly true of those gear shield lubricants having the proper E.P. additives. Proper implies additives that give lasting film strength beyond the inherent film strength of the petroleum phase.

AIR BEARINGS— LOW FRICTION*

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In recent months there has been a sharp focusing of interest on bearings that are lubricated with air. This interest is centered around the two major advantages of the use of air; the first, freedom from contamination by the lubricant, and the second, low friction.

It is rather obvious that if air is substituted for oil or grease in a bearing, the danger of dripping, soiling or contamination by the lubricant is completely eliminated. This is important in many applications dealing with food processing machinery, thread and textile machines and in the chemical industries. We will not be concerned here with this aspect of air-lubricated bearings. Rather, it is our purpose to describe the unique and sometimes amazingly low friction properties of these bearings. We then plan to establish methods for the quantitative analysis and performance prediction of these bearings, based upon the fundamentals of fluid dynamics.

Air lubricated bearings are presently used over wide ranges of speeds, from very low to as high as 80,000 to 100,000 rpm. They have been designed as both journal bearings and thrust bearings and have been lubricated by the normal hydrodynamic action of air or by the hydrostatic introduction of air to the bearing at elevated pressures. A considerable variety of designs is available to satisfy the needs of almost any type of application, producing low-friction bearings with reasonably good load-carrying capacities. Certain designs have also been used for the primary purpose of maintaining extremely close running tolerances between machine elements. Other designs have been developed to measure vanishingly small pressure differences, as low as 0.0004 inches of water.

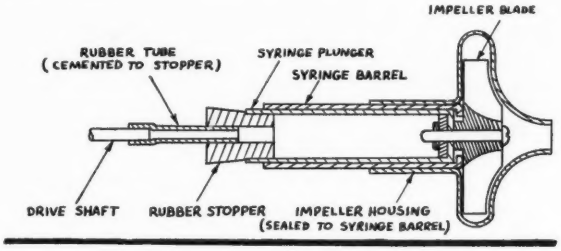
This all began many years ago near the end of the seventeeth century. It was then that Sir Isaac Newton conducted his great series of experiments[1]. One of these experiments was concerned with the resistance to motion of two concentric cylinders, when one cylinder was turned relative to the other, both being submerged in a liquid. Newton observed that for a constant temperature the frictional force was proportional to the relative speed of rotation, and to the swept area and inversely proportional to the radial clearance space between the cylinders, providing that this clearance space was small. (1): $F = kA\,(v/h)$. The constant of proportionality "k" depends upon the liquid and is now recognized as the absolute viscosity μ (mu). This equation (1) may be written as (2): $F = \mu A\,(v/h)$. As applied to a journal bearing of length "l" and radius "r," "A" becomes $2\pi rl$, v becomes r and the friction torque or moment $M = F \times r$, $M = \mu 2\pi rl\,(\omega r/h)\,r$, (3): $M = (2\pi r^3 l\mu\omega)/h$. Where "$\omega$" (omega) is the angular velocity in radians/sec, and "h" is the radial clearance in the bearing.

*Revision of a paper presented before the New York Academy of Sciences, January 16, 1953.

Albert Kingsbury[2] and others have demonstrated the accuracy of equation (3) when applied to air lubricated bearings. Kingsbury experimented with a bearing 6 inches in diameter, by 6¼ inches long in which was placed a short length of shaft weighing 50.5 lbs. Radial clearance about 0.0008". The load was carried without difficulty at shaft speeds above 250 rpm. Kingsbury measured coefficients of friction as low as 0.001. Equation (3) can be used for air lubrication even when the bearing is carrying a moderate load of a few lbs. per square inch, as long as a laminar flow condition prevails in the film. This is generally true if Reynolds number (vD/ν) for the film is less than 2000. ν(nu) is the kinematic viscosity of air; v is the surface velocity of the shaft; D is the air film thickness. Example: A bearing 3" diameter by 4" long running in atmospheric air at a speed of 1800 rpm and with a diametral clearance of 0.002" would have a friction torque as indicated by equation (3). Viscosity of air at atmospheric conditions is 0.018 centipoises or $1.45 \times .018 \times 10^{-7}$ lbs sec/in^2 (Reyns). $M = 2 \times \pi \times 1.5^3 \times 4 \times 1.45 \times .018 \times 10^{-7}\,[(1800x/60)\,2\pi]/.001$; M = .042 in lbs; Frictional horsepower loss in this bearing $= 2\pi MN/12x33{,}000 = 2\pi \times .042 \times 1800/12 \times 33{,}000 = (1/840)$ HP. An evaluation of the Reynolds number for the air film in this bearing would show: $R = [(1800/60) \times \pi \times 3] \times .001/.0232$, where the kinematic viscosity of air at atmosphere conditions is .0232 (in^2/sec). R = 12.2 which is much less than 2000, the value of Reynolds number which is usually considered as indicating the threshold of turbulent conditions in fluid flow. This value was originally determined by measuring flow in pipes. Recent unpublished experiments on journal and thrust bearings show that the critical Reynolds number for bearings may be closer to 1000 or even a little less.

Surprisingly enough, first quality air lubricated journal bearings may be purchased very inexpensively at the corner drug store! The dry hypodermic syringe is actually an excellent journal bearing capable of running extremely well with air as a lubricant[3]. Brubach has used these syringes as bearings for small centrifugal blowers running at 6000 rpm. Fig. 1. Perhaps his most spectacular application has been in the measurement of gas leaks at very low pressures. Fig. 2 shows the apparatus used for this purpose. The plunger of the syringe is caused to

rotate by air impinging upon scotch tape vanes. Due to this rotation, the plunger acts as an air bearing and is separated from the barrel by a hydrodynamic air film. Since the surfaces are separated by an air film the force that is then required to move the plunger along the axis of the barrel actually approaches zero. Any slight change in the pressure of the line connected to the barrel will therefore produce an instantaneous axial movement of the rotating plunger. As an illustration of the sensitivity of this apparatus, it was connected to a tank of 100 liter capacity. Then 0.1 cubic centimeter of air was introduced into the tank. Immediately the plunger moved a corresponding 0.1 cubic centimeter. The theoretical pressure increase resulting from the injection of 0.1 cc into 100 liters is about .0004 in H_20 or 0.01 mm of water and yet the low friction of the rotating plunger permitted it to respond instantly to this exceedingly small pressure differential.



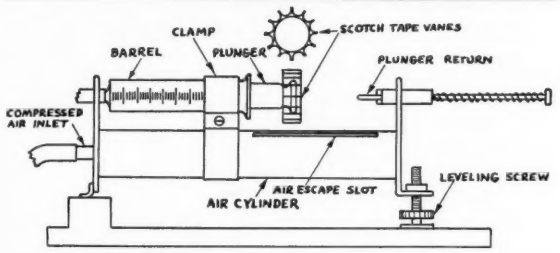


Fig. 1 (top) Centrifugal blower using hypodermic syringe as air-lubricated bearing.

Fig. 2 (bottom) Sensitive pressure-measuring apparatus using hypodermic syringe as air-lubricated bearing.

Where thrust type loads are encountered in machines and mechanisms, air can be frequently used as the lubricant. Fig. 3 shows a model of a Kingsbury type thrust bearing that runs very nicely on air. When the runner is turning the pivoted shoes tilt automatically until they develop a wedge-shaped film of air between the shoes and the runner, sufficient to carry the applied load. The runner in the model weighs 4 lbs. and there are 3 shoes, each approximately 1½ inches square. Spinning the runner by hand provides more than enough velocity to support this load. Based on the hydrodynamic theory an average value for the minimum film thickness under the shoes is (4): $h_o = \sqrt{(.066\mu v\ l)/Pavg}$, where μ is the absolute viscosity, v is the mean linear velocity of runner, l is the length of the shoe in the direction of motion, Pavg is the average loading pressure, and the corresponding friction force would be (5): $F = (.75\ \mu\ b\ l\ v)\ /h_o$, where b is the width of the shoe. For the model, with an average speed of 350 rpm, b = l = 1.5", mean shoe radius 1.75", viscosity of air = .018 centipoise = 1.45 x $.018 \times 10^{-7}$ reyns (lb. sec/in²), v = 350/60 x 2 π x 1.75 = 64.1 in/sec., area of 3 shoes 6.7 in², Pavg = W/area = 4/6.7 = 0.6 psi. In equation (4): $h_o = \sqrt{.066 \times 1.45 \times .018 \times 10^{-7} \times 64.1 \times 1.5/0.6}$, h_o = 0.00017 inches. The corresponding friction force, from equation (5), $F = .75 \times 1.45 \times .018 \times 10^{-7} \times 1.5 \times 1.5 \times 64.1/0.00017$, F = 0.00166 lbs. per shoe, and the resultant coefficient of friction "f," based on a mean shoe radius of 1.75": f = F/W = .00166/ 4/3 = .00125. Tests conducted on this model, measuring the rate of slowing down, give a value for the overall coefficient of friction, including windage, of approximately 0.002.

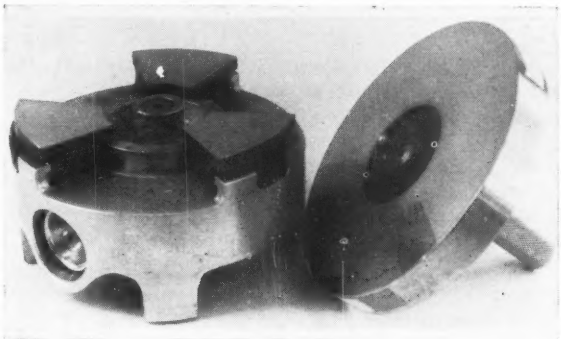


Fig. 3 Model of air-lubricated Kingsbury thrust bearing.

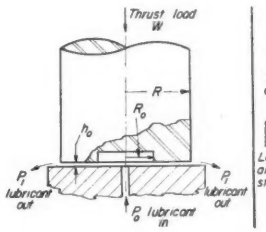


Fig. 4 (left) Elements of a hydrostatic step bearing.

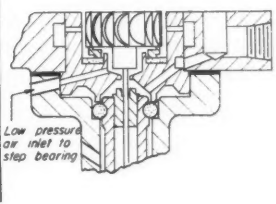


Fig. 5 (right) Air-lubricated step bearing on ultra-centrifuge (Courtesy of The Sharples Corp.).

When it may be desirable to carry the imposed thrust load and separate the bearing surfaces at all times by a film of air whether there is bearing rotation or not, it is possible to introduce air hydrostatically under pressure. Fig. 4 shows the arrangement of elements in such a bearing, called a "step" bearing. Equations 6, 7 & 8 based on the fundamentals of hydrodynamics permit the evaluation of supply pressure, P_o, volume of flow Q, and friction torque, M. These equations are derived in Ref. 4. (6): $W = P_o\pi/2\ [R^2 - R_o^2/\ln (R/R_o)]$, (7): $Q = P_o\ \pi\ h^3/6\ \mu\ \ln (R/R_o)$, (8): $M = 2\pi\mu\omega/h_o\ (R^4/4 - R_o^4/4)$.

Fig. 5 depicts an interesting application to an ultra centrifuge where the vertical load is supported on an air step bearing and the rotor is spun by air jets. This unit operates at a speed of approximately 80,000 rpm. The friction is so low that once the case is evacuated, and the driving air supply shut off, the rotor will continue to spin for many hours before coming to rest. With R = 3/8", R_o = 11/32", effective weight 1.86 lbs., shaft diameter 1/16", and subtracting the shaft cross-sectional area from the load-carrying area of the bearing, in equation (6), $1.86 = P_o\ \pi\ /2\ [(3/8)^2 - (11/32)^2/\ln$

1.091] — P_o [π (1/16)²/4], P_o = 4.62 psi. Actually 5 psi is used on this step bearing.

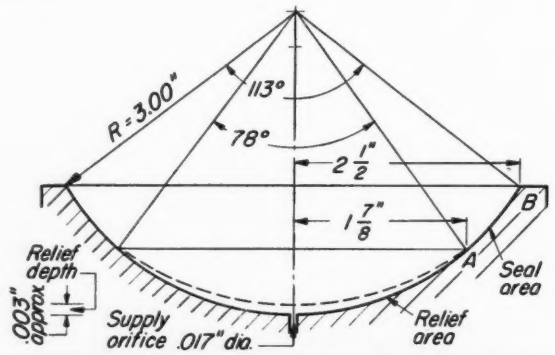
A very interesting model was built by the Sperry Gyroscope Co. to demonstrate the low friction properties of air lubricated bearings. This model consisted of a steel ball 6 inches in diameter supported in a cup. Fig. 6 supplies details of the construction. Calculations of air pressure and volume required using equations (6) and (7) were completely substantiated by experiment. They were P_o = 2.1 psi and with h_o = .001 inches, Q was 0.02 cfm. The friction was so low that once the ball was started spinning, it continued to rotate for hours. In reality it became a ball, freely suspended in space, turning without friction.

Hydrostatic lubrication itself generally leads to very low coefficients of friction, even with oil. A rather striking example is that of the Hale telescope on Mount Palomar, where the overall coefficient of friction, using a medium viscosity oil, is 0.000004. This telescope, weighing about one million pounds, is rotated by a 1/12 hp clock motor, which actually supplies more power than is required[5].

A recent design for an electrical dynamometer with a cradle weighing 1300 pounds[6], reports a coefficient of friction 0.00000075. Actually this is zero for all practical purposes—and was obtained with oil. Air under similar conditions would introduce even less friction.

It should be emphasized that the equations set forth are based upon the hydrodynamic theory of incompressible liquids and for greatest accuracy should be used with air only if the pressures involved are not greater than several pounds per square inch. Where greater loads are carried and unit pressures are higher the analysis should include the compressibility effect, since there may be significant changes in volume with these higher pressures as the air passes through the bearing.

To demonstrate how this may be done, equation (7) for a hydrostatic thrust bearing has been rederived, including this effect of compressibility. The dervation is given in Ref. 7. (9): $V_o = \pi h_o^3/6 \mu \ln R/R_o (P_0^2 - P_1^2/2P_0)$, where ln R/R_0 is the logarithm or R/R_o to the base e, V_o is the volume of flow at inlet conditions, P_o is the absolute pressure of the inlet air and P_1 the absolute pressure of the air at the exit. All other terms correspond to those of equation (7). Some experimental work is being done at Columbia University on this type of air-lubricated bearing as shown in Fig. 4. With R = 3 inches, R_o = 1 inch, h_o the film thickness = 0.0015 inches, P_o the supply pressure = 30 psi gage or 44.7 psi absolute, and P_1 the ambient pressure, room pressure or 14.7 psi absolute, depth of recess 0.02 inches. At the time the data were taken the bearing was supporting a load of 375 pounds and the flow of air was measured as 2,440 cubic inches per minute of free air (standard pressure and temperature). With pressures this high, the equations such as 6, 7 & 8 should not be used as the compressibility of the air makes them inaccurate. For example, using equation (7): $Q = 30 \times \pi \times .0015^3/ 6 \times .018 \times 1.45 \times 10^{-7} \times \ln 3$, $Q = 18.5$ in³/sec, or $Q = 18.5 \times 60$; Q = 1,110 cubic inches per minute. Using the same data in equation (9) which allows for the compressibility action, $V_o = \pi \times .0015^3/6 \times .018 \times 1.45 \times 10^{-7} \ln 3 (44.7^2 - 14.7^2/2 \times 44.7)$; V_o = 12.3 cubic inches per second, which when converted to its corresponding volume of free air is: $V_1 P_1 = V_0 P_0$, or $V_1 = V_0 (P_0/P_1)$, V_1 = 12.3 x 44.7/ 14.7 = 37.4 cubic inches per second, or V_1 = 2,244 cubic inches per minute. Thus equation (9) serves as an excellent estimate of the actual flow which was measured as 2,440 cubic inches per minute.



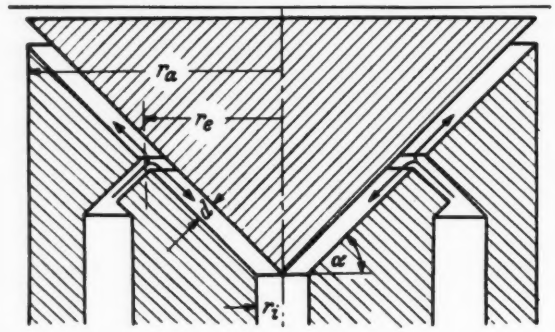


Fig. 6 (top) Details of step bearing for steel ball (Courtesy of The Sperry Gyroscope Co.).

Fig. 7 (bottom) Air bearing design of Gottwald & Vieweg (Courtesy of Zeitschrift fur Angewandte Pysik.).

Some further considerations regarding air-lubricated bearings may be found in a recent German paper[8]. Fig. 7 is taken from that paper and shows a conically shaped bearing supported by air under hydrostatic pressure. The air is supplied through the circumferential groove at the middle of the bearing or through a belt of holes at the same location. This is in reality an elaboration of the step bearing described earlier. Before, with the simpler design, the air flowed only radially outward. With the design shown in Fig. 7 the air flows both outward and inward. The authors have tested this and similar bearings and report good correlation between theory and measurement.

It should be obvious that air-lubricated bearings can be constructed in a number of forms to match the peculiar operating demands of a wide variety of applications. Air bearings have certain major advantages for many types of work. Within their limitations then they do represent a relatively new solution to the general problem of bearing design and analysis.

It is hoped that this paper has been able to make manifest the principles underlying this development, and perhaps point the way to further uses and application. Our experience has already indicated

that the range of application of air lubrication, is limited only by the vision and imagination of the designer.

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Section News

MONTREAL: October meeting — Presentation of section's charter to Section Chairman A. E. Bowden, Steel Co. of Canada, Ltd., by W. C. Campbell (ASLE President), Bell Telephone Laboratories, after which Dr. Campbell presented a paper entitled Solid Lubrications. (Submitted by F. J. Pearce, Sec'y-Treas.)

PHILADELPHIA (Supplement to Feb. '53 LE): For the second consecutive year, a helpful seminar on industrial lubrication engineering was sponsored by the Philadelphia Section, with members of the Educational Committee as follows: C. R. Schmitt, E. F. Houghton & Co., Chrmn.; M. Petronio, Frankford Arsenal; J. L. Beatty, L. R. & J. L. Beatty Co.; S. F. Wedemeyer, Esso Standard Oil Co.; J. H. Fuller, E. I. duPont deNemours Co.; W. E. Rigot, U.S. Steel Corp.; and L. W. Miller, Scott Paper Co. Held February 10 through March 10 (on consecutive Tuesdays) at the Bellevue-Stratford Hotel, the seminar included detailed explanations and instructions on such subjects as lubricant dispensing equipment, planning and installing complete lubrication maintenance programs, theory and application of drawing compounds and cutting oils, and other allied subjects. Instructors for the course were industrial lubrication engineers and specialists with long practical experience, the closing meeting featuring a panel discussion session in which experts answered any unusual lubrication application problems. Certificates of attendance and bound copies of instruction data were presented to those attending (39). To partially defray expenses, a nominal fee was charged for registration, with the major portion of costs absorbed by the Section. (Submitted by C. R. Schmitt, Chrmn., Educational Committee.)

BALTIMORE: September meeting —H. O. Moffett, Pedrick Piston Ring Co., presented a paper entitled A Discussion Of The Evolution, Design, Selection & Lubrication Of Piston Rings.

October meeting—T. W. Langer, Carbide & Carbon Chemicals Co., presented a paper entitled Some Industrial Experiences With Synthetic Lubricants, abstracted as follows:

"During the past decade increasing use has been made of synthetic lubricants from a variety of special, man-made molecules, including polyalkylene glycol derivatives, diesters, silicons, and flourocarbons. These materials differ considerably among themselves and from petroleum lubricants with regard to physical and chemical characteristics. Of the various synthetic types, the polyglycol derivatives are probably most widely used in industry because of their suitability and versatility.

"Several years of practical experience have demonstrated that outstanding results in many industrial applications are associated with distinctive qualities of polyglycols. Case records illustrate examples involving high temperatures, low temperatures, heavily loaded gears, metal working, molding operations, compressors, vacuum pumps, internal combustion engines, solvent action, hydraulic fluids, and other conditions. The use of synthetic lubricants is often economically justified by improved operation of mechanical equipment or by substantial reduction in maintenance expenses, compared to conventional lubricants. The introduction of new machines and the trend towards greater efficiency will undoubtedly further the utilization of synthetic lubricants."

November meeting—A plant inspection trip thru Consolidated Gas & Electric Co., with emphasis upon application of a lubrication program to mechanical and electrical equipment. (Submitted by W. W. Witmer, Sec'y-Treas.)

BOSTON: October meeting — W. E. Campbell (ASLE President), Bell Telephone Laboratories, presented a paper entitled Fretting Corrosion. ASLE lapel pins and leather pocket secretaries were presented by A. E. Baker to J. R. Clarke, Jr., and A. S. McNeilly in appreciation of their services at the Boston Annual Meeting.

November meeting — E. L. H. Bastian, Shell Oil Co. (New York), presented a paper entitled Cutting Fluids. **(Continued on page 322)**

ELECTROGRAPHIC SPOT TESTING OF BEARING SURFACES*

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Research Laboratories Div.
Detroit 2, Mich.

It has been said, "One of the most useful sources of engineering information is the scrap heap." Certainly a great deal can be learned about bearing design from the inspection of used bearings. Fatigue patterns, dirt tracks, eroded areas, burnished areas, varnished areas — these give valuable clues regarding many matters of concern to bearing designers and lubrication engineers. Even the backside of a bearing may have an important story to tell.

There are, however, a number of questions that cannot be settled by visual examination. The eye, for example, sees a pebbly pock-marked surface. Is it the result of erosion or of grit? The eye sees blackened areas. Are they deposits of carbon or the result of sulfur corrosion? These are questions that the visual observer cannot answer. There are many such questions. They may concern the composition of a bearing alloy, or the segregation of the constituents, or the porosity of an overlay, or the identification of embedded particles. The determination of these questions generally requires elaborate chemical or metallographic or spectrographic study.

The purpose of this paper is to describe a simple technique — electrographic spot testing — which provides reliable answers to such questions. It is a completely straight-forward technique, requiring no highly trained personnel or elaborate equipment. It is quick; it is non-destructive; and it provides a permanent record. It will, for example, not only identify embedded particles; it will also show how many of them there are, what are their relative size, and exactly where they are located. For many purposes, it yields results as good or better than those obtained by radioactive techniques, but without the complications attendant upon handling radioactive materials. This combination of simplicity, rapidity and reliability makes electrographic spot testing an extremely useful tool for studying bearings.

DEVELOPMENT OF SPOT TESTING METHODS: Spot testing is as old as the practice of analytical chemistry. In its simplest form, it involves merely the preparation of a solution of the material to be identified and the identification of the dissolved material by means of a reagent which gives a characteristic color indication. The test is conclusive if the color indication is specific for the material; otherwise check tests must be made with other reagents to eliminate the possibility of similar color indications which may be caused by interferring materials. Tests of this kind have long been used for identifying bearing white metals. Some typical tests are given in Table I.

The limitation of simple spot testing is that it is suitable only for identifying materials. Where the material to be studied is non-uniform, and it is desired to study both the composition and distribution of the constituents, a refinement is required in analytical methods. This was provided by the "Chemical Contact Print Method" of Baumann (1906).[1] The method uses paper or other inert absorptive material which is moistened with a dissolving agent. This moistened paper is pressed into contact with the surface to be studied. The dissolving agent attacks the surface, producing soluble products which diffuse into the paper. Color reactions are then carried out on the paper, and the distributive pattern of inclusions and other non-uniformities is preserved. The method is capable of yielding excellent results in the hands of an expert, but it is rather tricky to control, inherently slow, and subject to loss of distributive pattern due to lateral diffusion of the soluble products.

An important improvement, applicable to surfaces which are conducting and ionizable, was introduced by Glazunov (1929).[2] The improvement consists in the use of electrolytes instead of dissolving agents and of electro-deposition instead of diffusion. Paper moistened with a suitable electrolyte is pressed between the material to be studied and an inert conductor such as aluminum or platinum foil. Metal ions are then caused to migrate into the paper as a result of internal electrolysis or by making the material anodic and the backing conductor cathodic. Intimate contact between the various elements of the sandwich may be assured by the use of a piece of soft rubber behind the backing conductor, and the entire sandwich may be squeezed together under pressure in a vise or other clamping device. Prints are developed, as before, by the use of suitable reagents. The advantages of the method are that it uses inert electrolytes and hence it is easy to control, that it is rapid — a finished print may be prepared in a few seconds — and hence lateral diffusion is minimized. Because the objective of the method is the exact reproduction of surface features in the form of a print, Glazunov called it the "Electrographic Method."

The earliest known application of Glazunov's "Electrographic Method" to the study of bearing surfaces was made by the late Maurice J. Mulligan (1900-1950) at the Research Laboratories Division of General Motors Corporation. His first bearing print (1936), showing iron particles embedded in a babbitt bearing, used filter paper with potassium

*Sponsored by the ASLE Technical Committee on Bearing Lubrication, and presented at the ASLE 8th Annual Meeting, Boston, April 14, 1953.

nitrate as the electrolyte and potassium ferrocynanide as the reagent.

APPARATUS FOR SPOT TESTING BEARINGS: One of the virtues of spot testing is that it does not require elaborate apparatus. Satisfactory prints can be obtained with the following simple materials:

(1) PAPER: Any good grade of white paper may be used for making bearing prints. Filter paper has been much used, but denser, less absorbent papers give clearer prints. The authors have obtained good results with so-called "second sheets" used for carbon copies. The sharpest prints are obtained with gelatin-coated papers such as the imbibition paper used for color transfer work in photography. Such papers tend to stick to the bearing surface and consequently must be peeled off carefully to avoid skinning the print. Cellophane gives transparent prints which may be used as slides.

(2) ELECTROLYTES & REAGENTS: The various electrolytes and reagents that have been found to give satisfactory bearing prints are described elsewhere in the paper. These are available from chemical supply houses. Only a few ounces of reagent is needed for making a large number of prints, and since most reagents store well when kept in a cool dark place, they may be used over again if reasonable care is taken to avoid contamination.

(3) BACKING MATERIALS: Aluminum foil, about 0.002 inch thick, is a satisfactory conducting backing. This may be backed up by a piece of soft rubber, about the same grade and thickness as an inner tube, or preferably by a piece of sponge rubber. The rubber backing permits the print to conform to small irregularities in the bearing surface.

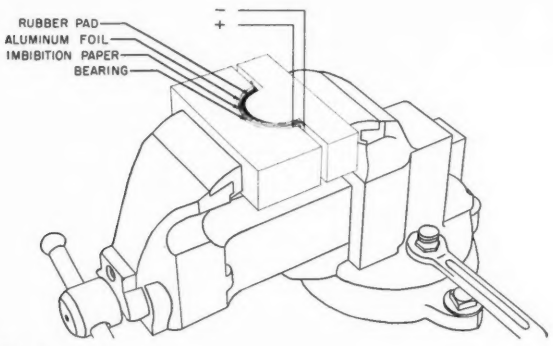

Fig. 1

(4) BLOCKS: Wood blocks, shaped as shown in Fig. 1, are a convenient means of holding together the various elements of the sandwich when making a spot test of an insert bearing. A separate set of blocks is needed for each size of bearing to be spot tested. In making the blocks, allow sufficient clearance between the semi-circular portions to contain the entire spot testing sandwich.

(5) CLAMPING MEANS: Since most spot tests can be made in only a few seconds, the sandwich may be held together under light pressure in the hands. While this method is satisfactory for most purposes, the best and sharpest prints are obtained when the sandwich is squeezed together under pressure. Several investigators have used an ordinary laboratory press as the clamping means. A bench vise is just as satisfactory.

(6) CURRENT SOURCE: While most materials will give satisfactory prints by internal electrolysis, it will generally be desirable to use an external current source. An ordinary 6-volt dry battery is adequate for most purposes.

(7) PANS: At least three pans are needed for chemicals — one for the electrolyte, one or more for the reagent or reagents, and one for wash water. The pans should be of glass, enamelware, or other inert material and should be large enough to accommodate the print papers. Photographic trays are very satisfactory. The pans should be thoroughly washed following each use to prevent contamination of the chemicals.

If spot testing of bearings is to be carried out frequently, certain refinements of the above materials will add to the convenience of the test.

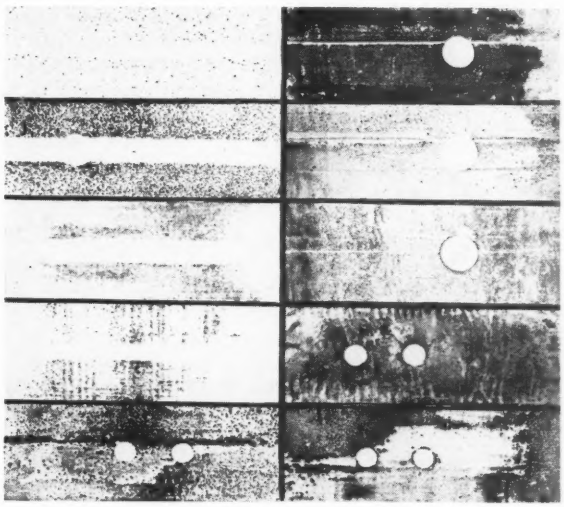

Fig. 2 (top left), Fig. 3 (second left), Fig. 4 (third left), Fig. 5 (forth left), Fig. 6 (bottom left), Fig. 8A (top right), Fig. 8B (second right), Fig. 8C (third right), Fig. 9 (fourth right), Fig. 10 (bottom right).

APPLICATION TO BEARING SURFACES: The following are some typical examples of the application of electrographic spot testing to bearing surfaces.

(A) IDENTIFICATION OF WHITE METALS: Electrographic spot testing provides a means of quickly identifying the constituents of white metals and other bearing alloys. Because of the great sensitivity of the available reagents, only a very small number of metallic ions need be removed from the bearing surface, and the test may therefore be said to be non-destructive. Considerable attention should be given to the selection of reagents that are specific for the metal sought and that do not give spurious color indications from interferring metals. In some cases, this means that several different reagents must be tried in order to eliminate possible spurious indications.

Quantitative analysis of bearing alloys may be carried out electrographically if the procedure is standardized and if suitable calibrating specimens are available. In general, however, the electrographic method is most satisfactory as a means of qualitative analysis.

(B) EMBEDDED PARTICLES: When used

bearings are examined, there are usually found embedded in their surfaces particles of foreign material. Electrographic spot testing provides a convenient means of identifying these particles and of studying their distribution and relative sizes.

Fig. 2 is an electrographic print prepared from a lead-base babbitt bearing which contained a relatively small number of iron particles. These iron particles were worn from the journal by the abrasive action of particles of road dust (largely silicates) embedded in the bearing. The iron particles were therefore the result rather than the cause of journal wear. No satisfactory electrographic test has yet been developed for silicates, but an estimate of the amount of silicates embedded in a bearing may be obtained by comparing the weight of a bearing before and after washing with hydrofluoric acid.

Fig. 3 is a print obtained from a lead-base babbitt bearing which had been operated for a short time with very dirty oil. The distribution of iron particles over the bearing surface is very dense, but individual particles can still be distinguished. This print may be compared with Fig. 4 which was obtained from a lead-base babbitt bearing that had been run for a considerable time on very clean oil. The hazed appearance of the print indicates that there has been some pick-up of extremely fine iron from the journal surface. The area of greatest iron density is the area of maximum load, and the individual particles are so fine that they cannot be distinguished.

Fig. 5 is a print from a lead-base babbitt bearing that had been run in an engine for only twenty minutes on a break-in schedule. The iron particles are concentrated in longitudinal streaks corresponding to the extremely minute irregularities in the broaching tool used for finishing the bearing. In this case, fine abrasive particles, probably from honing the cylinders, became embedded in the bearing, and the iron streaks shown in the print are composed of particles of iron worn from the journal where it touched these embedded abrasive particles in the bearing.

Fig. 6 is a typical print for iron obtained from an automotive connecting-rod bearing after approximately 5000 miles of service under dirty operating conditions. The concentration of iron particles in a circumferential line at the edge of the oil holes is characteristic of connecting-rod bearings which are supplied with oil by means of a passage drilled through the crankshaft to the main bearing. Fig 7 shows that abrasive particles entrained in the oil flowing from the main bearing to the connecting-rod bearing are acted upon by centrifugal force due to crankshaft rotation so that they flow along that part of the drilled passage farthest from the axis of rotation. They thus emerge from the drilled hole at the edge nearest the main bearing from which oil is being supplied. Once in the bearing, the particles are urged in the direction of the falling pressure gradient, the oil-film pressure distribution being such that the particles move from right to left in the figure. There is thus formed in the bearing a step which coincides with the edge of the oil hole in the journal. A matching step is found on the journal.

Fig. 8 shows three iron prints taken from bearings which have been run in three identical engines. Fig. 8A shows the effect of running under dirty conditions without a filter. Fig. 8B shows the effect of running under the same conditions with a by-pass filter. Fig. 8C shows the effect of running under the same conditions with a full-flow filter.

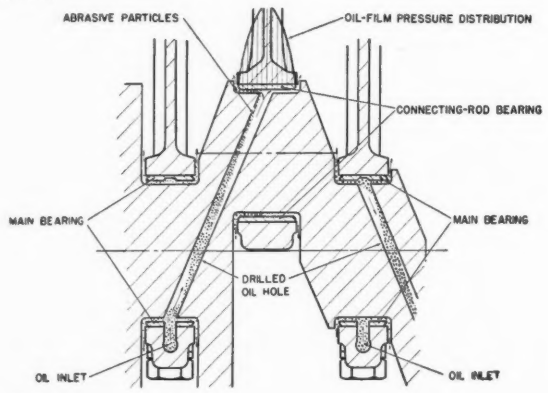

Fig. 7

(C) POROSITY OF PLATED OVERLAYS: Many heavy-duty bearings are now made by electrodepositing a thin layer of soft white-metal alloy on copper-lead, silver, or other hard bearing material. The electrodeposited white metal may be coplated lead-tin or triplated lead-tin-copper. Such plated overlays, as they are called, are made thin in order to obtain satisfactory fatigue durability and to obviate the need for final boring. In addition, the plated overlay protects the underlying bearing material from chemical attack by organic acids, sulfur compounds, and other corrosive materials in the oil. With extremely thin overlays, attention must be given to the porosity of the plating, because any porosity will permit corrosive materials to attack the underlying material.

Fig. 9 is a print obtained from a plated bearing. The overlay was coplated lead-tin (90 Pb, 10 Sn) about 0.0002 inch thick deposited on copper. The bearing was spot tested for copper. The resulting print is positive, indicating considerable porosity of the lead-tin overlay.

(D) BOND FAILURE OF PLATED OVERLAYS: Bearing failures caused by poor bond were at one time frequently reported, but it is now known that many of these so-called bond failures were really fatigue failures of thick babbitt. With thin plated white-metal overlays, bond failure appears to be very rare. The authors have encountered only one instance of bond failure of an overlaid bearing. An electrographic print for lead taken from this bearing is shown in Fig. 10. The area of bond failure is in the heavily loaded portion of the bearing around the oil hole. A smaller area of bond failure is shown in the lower left corner of the print. Notice also the circumferential line from which the overlay has been abraded by abrasive particles at the edge of the oil hole.

(E) METAL TRANSFER: Electrographic spot testing is frequently more convenient than radioactive techniques as a means of studying metal transfer between rubbing surfaces. Unlike radioactive methods, however, it can be used only when the rubbing surfaces are of dissimilar metals.

Fig. 11 shows a spot test of the tracks left by a hemispherically ended tin stylus sliding on an aluminum plate. Track "A", which was made with a normal load of one-half pound, is typical of the metal transfer obtained with smooth sliding. Track "B", which was made with a normal load of 3½ pounds, is typical of "stick-slip" sliding.

Fig. 12 is a print showing the relative amounts of metal transfer obtained with dry and lubricated sliding. Track "A" is the track made by a copper stylus rubbing on a dry steel surface, while track "B" is the track made by the same parts flooded with lard oil.

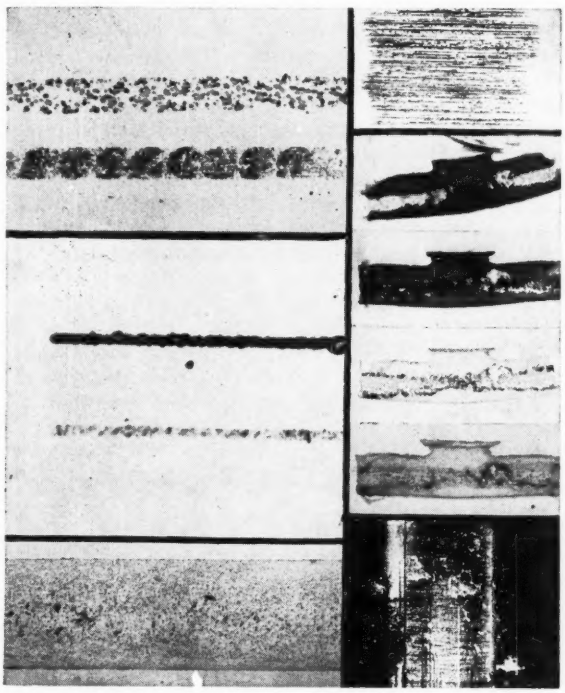

Fig. 11 A & B (top left), Fig. 12 A & B (middle left), Fig. 13 (bottom left), Fig. 14 (top right), Fig. 15 A, B, C, D (middle right), Fig. 16 (bottom right).

(F) SEGREGATION OF ALLOYS: One of the most interesting applications of electrographic spot testing is found in studying the segregation of bearing alloys. For such work, electrographic prints are superior to ordinary metallographic prints, because they permit positive identification of the segregated metal. For best results, the paper should be virtually dry to minimize lateral diffusion. If sufficient care is used, the print will be very sharp, and the resolution will be equal to that of a metallographic print.

Fig. 13 is an enlarged portion of an electrographic print showing segregation of a heavy metal in an experimental bearing alloy. The test surface was prepared by ordinary machining; preparation by polishing and etching may also be used but is not necessary.

(G) CORROSION: Certain materials, notably silver and copper are susceptible to attack by active sulfur compounds used as oxidation inhibitors in lubricating oils. White-metal overlays are not attacked by sulfur, but if the overlay is broken through by fatigue cracks or dirt scratches, the underlying material is exposed to sulfur attack.

Fig. 14 shows an electrographic print for sulfide taken from an indium coated silver bearing. Wherever the indium coating has been scratched through by dirt particles, the silver has been exposed to attack by sulfur compounds in the oil. The silver sulfide is reduced by cathodic action.

(H) WEAR: Electrographic spot testing is frequently a convenient means of studying the wear of protective platings. A typical example is shown in Fig. 15, which is a print obtained from a ball pocket of a silver-plated Monel S ball-bearing separator. Fig. 15A is a spot test for silver, showing the absence of silver in the areas of high-load contact; Figs. 15B and 15C are spot tests for nickel and copper respectively, these metals being the principal constituents of Monel S; Fig. 15D is a spot test for iron, showing considerable transfer of iron as a result of scoring of the steel ball on the Monel S.

Fig. 16 is a print for tin obtained from a portion of a tin-plated piston skirt. Localized wear of the tin plate is shown by the vertical lines of low density.

IDENTIFICATION TESTS FOR BEARING METALS

A. Lead-Base Bearing Metal
   1. Clean bearing surface with acetone.
   2. Place one drop of 50 per cent glacial acetic acid on bearing surface.
   3. Add one drop of 10 per cent potassium iodide.
   4. Yellow reaction indicates lead-base bearing metal.

B. Tin-Base Bearing Metal
   1. Clean bearing surface with acetone.
   2. Place one drop of 20 per cent hydrochloric acid on bearing surface.
   3. Add one drop of aqueous cacotheline.
   4. Violet reaction indicates tin-base bearing metal.

NOTE: Almost all lead-base bearing metals contain some tin and will therefore give a slight violet reaction with Test B.

Table I

SPOT TESTS FOR VARIOUS MATERIALS: In the following condensed catalog of spot tests for various materials, interferring materials have been given whenever they are known. When interferring materials are not given, the test should be checked against possible interferring materials to insure that the color indication is not spurious.

(A) ARSENIC: Electrolyte, 5% potassium nitrate; Reagent, silver nitrate; Color, red brown; Interferring Materials, chromates, ferrocyanides, and ferricyanides.

(B) BISMUTH: Electrolyte, 5% potassium nitrate, or 10% potassium iodide, or combination of both; Reagent, 10% potassium iodide; Color, orange; Interferring Materials, lead, mercury.

(C) CADMIUM: (1) Electrolyte, paper soaked in freshly prepared alcoholic solution of diphenylcarbazide and then soaked in 5% potassium nitrate; Reagent, ammonia (either gaseous or in aqueous solution); Color, purple on pink background; Interferring Materials, copper, lead, mercury. (2) Electrolyte, 5% potassium nitrate; Reagent, dilute solution of sodium sulfide; wash paper in dilute acetic acid to remove excess sodium sulfide; Color, yellow; Interferring Materials, zinc and elements forming black sulfides.

(D) CHORMIUM: (1) Electrolyte, paper soaked in 5% potassium nitrate and in acetic acid solution of diphenylcarbazide; Reagent, acetic acid

solution of diphenylcarbazide; Color, magenta (electrolyze for a few seconds only, because formation of yellow potassium chromate may mask magenta color); Interferring Materials, mercury, molybdenum, vanadium. (2) Electrolyte, aqueous solution of 5% sodium nitrate and 5% sodium phosphate; Reagent, diphenylcarbazide (magenta), benzidine (blue), silver nitrate (red), or lead acetate (yellow); Color, indicated above. (3) Electrolyte, 5% potassium sulfate or potassium nitrate; Reagent, 3% hydrogen peroxide; Color, yellow, changing to violet.

(E) COBALT: (1) Electrolyte, 5% sodium fluoride; Reagent, saturated acetone solution of potassium thiocyanide; Color, blue; Interferring Materials, copper or nickel in large quantity. (2) Electrolyte, sodium carbonate; Reagent, 1% alkaline solution of dithiooxamide and ammonia; Color, brown; Interferring Materials, nickel (blue) and copper (black).

(F) COPPER: (1) Electrolyte, 5% potassium nitrate or 5% Rochelle salts; Reagent, 5% ammoniacal benzoin-oxime in alcohol; Color, green. (2) Electrolyte, 5% potassium nitrate; Reagent, 0.5% dithiooxamide in alcohol; Color, black; Interferring Materials, cobalt (brown), nickel (blue), silver (brown). (3) Electrolyte, 5% potassium nitrate; Reagent, 5% potassium ferrocyanide; Color, reddish brown; Interferring Materials, iron (blue).

(G) IRON: (1) Electrolyte, 5% potassium nitrate plus equal volume 5% potassium ferrocyanide; Reagent, 5% potassium ferrocyanide; Color, blue (may be intensified by hydrochloric acid fumes); Interferring Materials, large portions of metal salts giving colored precipitates with potassium ferrocyanide. (2) Electrolyte, 5% potassium nitrate; Reagent, potassium thiocyanide; Color, red (may be intensified by hydrochloric acid fumes); Interferring Materials, same as above. (3) Electrolyte, 5% potassium nitrate; Reagent, 5% potassium ferrocyanide; Color, blue (may be intensified by hydrochloric acid fumes); Interferring Materials, chromium.

(H) LEAD: (1) Electrolyte, 5% potassium sulfate; Reagent, stannous chloride and potassium iodide; Color, orange red, discoloring on standing; Interferring Materials, bismuth. (2) Electrolyte, 5% potassium nitrate; Reagent, 10% potassium iodide; Color, yellow; Interferring Materials, bismuth and copper. (3) Electrolyte, 5% potassium nitrate; Reagent, 1% potassium chromate in normal acetic acid; Color, yellow; Interferring Materials, silver.

(I) MAGNESIUM: Electrolyte, dilute sodium hydroxide plus sodium nitrate; Reagent, iodine in potassium iodide decolorized to lemon yellow with sodium hydroxide immediately before immersion of the paper; Color, dark reddish brown (fades on standing).

(J) NICKEL: Electrolyte, 5% potassium nitrate; Reagent, 1% dimethylglyoxime in conc. ammonium hydroxide; Color, scarlet; Interferring Materials, iron, cobalt, large amounts of halogens and nitrates.

(K) SILVER: (1) Electrolyte, 5% potassium nitrate or 5% potassium sulfate; Reagent, 5% potassium chromate; Color, brick red. (2) Electrolyte, 5% potassium nitrate or 5% potassium sulfate; Reagent, saturated acetone solution of p-dimethylaminobezalrhodanine; Interferring Materials, mercury, gold, platinum, palladium, copper.

(L) SULFIDES: Electrolyte, 15% lead acetate plus 10% sodium carbonate; Reagent, none; Color, brown to black, according to density of film. Note: The print is made by cathodic reduction (Reverse Polarity).

(M) TIN: (1) Electrolyte, soak paper in sodium phosphate-ammonium molybdate solution, blot dry, wet with 10% nitric acid, wash with tap water, and soak in potassium nitrate; Reagent, dilute ammonium hydroxide solution; Color, blue; Interferring Materials, antimony, cobalt, vanadium, iron, chromates, copper in large amounts. (2) Electrolyte, aqueous solution of cacotheline, acidified slightly with hydrochloric acid; Reagent, none; Color, violet; Interferring Materials, sulfides, thiosulfates, antimony salts, vanadium.

(N) ZINC: Electrolyte, 5% potassium nitrate; Reagent, dilute solution sodium sulfide (wash paper in dilute acetic acid); Color, yellow; Interferring Materials, cadmium and elements forming black sulfides.

The above are only a few of the available tests. Additional tests may be found in Feigl[3], Hunter, Churchill and Mears[4], and Hermance and Wadlow[5].

No satisfactory electrographic tests are known for the metals aluminum, beryllium, and indium, or for refractory materials such as alumina and silicon carbide.

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ACKNOWLEDGEMENTS: Many of the techniques described in this paper were either developed or suggested by the late Maurice J. Mulligan (1900-1950). It is the authors' hope that the paper will serve as a small memorial to his pioneer efforts.

Sincere thanks are due to Messrs. A. F. Underwood and L. Withrow for their constructive comments and encouragement.

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UNITS OF VISCOSITY AND THEIR CONVERSION

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Many years ago Sir Isaac Newton defined viscosity in very simple terms ("Principia," London, 1686). He used two concentric cylinders, submerged in water, and revolved one inside of the other. If the radial clearance or film thickness is called "h," and the swept area is called "A", and the difference in linear velocities of the two surfaces is called $\triangle V$, Newton observed that for a constant temperature, the force required to maintain motion and overcome the resistance to shear of the liquid was (1): $F = K \times A \times \triangle V/h$, where K is a proportionality constant, peculiar to the liquid being used. This factor K is a characteristic constant for each liquid and is now recognized as the actual coefficient of viscosity or absolute viscosity of the liquid. It is identified by the Greek symbol μ (mu). Thus, (2): $F = \mu A \triangle V/h$, or solving for μ, (3): $\mu = Fh/A\triangle V$. The dimensions of μ, the absolute viscosity, can be obtained by subsituting the dimensions of the terms on the right hand side, thus: μ = (Force x Dist)/(Dist^2 x Dist/Time) = (Force x Time)/Dist^2, or in English units μ = (lbs. x sec)/in^2. This is called the "Reyn." This is a large unit and recently, one millionth of this unit has been suggested, called the "Micro-Reyn." In metric units μ = (Dynes x Sec)/cm^2 called the "Poise," or for a more practical unit, one hundredth of this unit is used, called the "Centipoise."

CONVERSION FROM ONE SYSTEM OF UNITS TO ANOTHER: Keep in mind that there are two relationships in general, for all conversions. One is "size of," and the other is "number of." For example, One foot = 12 inches, but, Number of inches = 12 x Number of feet. Thus One lb. = 453 grams x 980 cm/sec^2 = 444,000 dynes. And the number of dynes = 444,000 x number of lbs. (A). Also number cms^2 = 2.54^2 x number ins^2 (B). Divide (A) by (B) No. dynes/cm^2 = 444,000/2.54^2 x No. lbs/in^2. Multiply both sides by secs., and No. (dynes x secs)/cm^2 = No. (lbs x sec)in^2 x 444,000/2.54^2.

But by above definitions, (dynes x secs)/cm^2 = Poises, and (lbs x sec)/in^2 = Reyns. Therefore, No. Poises = 444,000/2.54^2 x No. Reyns. Or, No. Poises = 68,750 No. Reyns. Or finally, (4): No. Reyns = 1.45 x 10^{-5} No. Poises. Also, (5): No. Reyns = 1.45 x 10^{-7} No. Centipoises. Also, (6): No. Micro-Reyns = 0.145 No. Centipoises.

For example, if an oil has an absolute viscosity of 300 centipoises it would have a viscosity of 3 poises, or a viscosity of 435 x 10^{-7} reyns, or a viscosity of 43.5 micro-reyns.

Consider the viscosity of some typical fluids, at a temperature of 70 F.

Fluid	Centipoises	Reyns	Micro-Reyns
Honey Approx.	1500	2175 x 10^{-7}	217.5
SAE 50 (heavy)	800	1160 x 10^{-7}	116
Glycerine	500	725 x 10^{-7}	72.5
SAE 30 (medium)	300	435 x 10^{-7}	43.5
Olive Oil	100	145 x 10^{-7}	14.5
SAE 10 (light)	70	101 x 10^{-7}	10.1
SAE 5 (x light)	32	46.5 x 10^{-7}	4.65
Ethylene Glycol	20	29 x 10^{-7}	2.9
Mercury	1.5	2.17 x 10^{-7}	.217
Turpentine	1.45	2.1 x 10^{-7}	.21
Water	1.00	1.45 x 10^{-7}	.145
Octane	.54	.78 x 10^{-7}	.078
Air	.018	.026 x 10^{-7}	.0026

The viscosity just described is the kind called absolute viscosity. It is measured by using concentric cylinders, as did Newton, or by oscillating discs, or by flow through long capillary tubes, or by falling spheres in free liquid or by the rolling ball type of viscometer.

KINEMATIC VISCOSITY: This type viscosity is useful in that it is easily and accurately measured in the laboratory, it is significant in the analysis of turbulence in bearings, and is also found as part of the system of converting viscosity in Saybolt Second units of absolute viscosity. Commercial instruments that measure kinematic viscosity are relatively simple to build and operate and consist of short tube, capillary-type viscometers in which flow is produced because of the "head" of fluid acting. Commercial units are known as Ubbelohde, the Fitz-Simons, the Otswald, etc. (See ASTM Specification D445).

Kinematic Viscosity = Absolute Viscosity $\div$ Mass density. Thus, ν (nu) = μ (mu) $\div$ ρ (rho). Thus, (7): $\nu = \mu/\rho$, or (8): $\mu = \nu x \rho$. Units of kinematic viscosity in the metric system are "stoke," or 1/100 of a stoke called "centistoke."

In the metric system it is fortunate that the number for mass density is the same as for specific gravity. Thus if an oil has a viscosity of 3 poises and a mass density of 0.85, its kinematic viscosity is ν (stokes) = μ(poises)/ρ, or $\nu = 3/.85 = 3.53$ stokes. Also ν(centistokes) = μ(centipoises)/ ρ, or ν = 300/.85 = 353 centistokes.

SAYBOLT VISCOSITY: This is a term applied to measurements made on a commercial type instrument (See ASTM Specification D88). It measures something resembling kinematic viscosity but the deviation becomes rather large at values below 100 secs. The standardization of these instruments has brought about a reasonable degree of uniformity, but as Dr. Hersey puts it, at the risk of perpetuating their complications. Herschel[1] has shown that the conversion can be represented with sufficient accuracy by the equation (9): $\nu = 0.22t - 180/t$, where

t = Saybolt seconds and ν = centistokes (A more accurate conversion can be obtained from ASTM Standard D446).

EXAMPLE: If an oil has a viscosity of 100 Saybolt Universal Seconds at 175 F., and a mass density (specific gravity in metric system) of 0.85, the viscosity in other units is as follows. Saybolt seconds = 100 S.U.S. (Saybolt Universal Seconds), Kinematic vis. $\nu = 0.22 \times 100 - 180/100$ (from equation 9), $\nu = 20.2$ centistokes. Absolute vis. $\mu = \nu \times \rho$ (from equation 8), $= 20.2 \times 0.85$, $\mu = 17.2$ centipoises. Or Absolute vis. $\mu = 0.145 \times 10^{-7} \times 17.2$ reyns (from equation 5), $\mu = 24.9 \times 10^{-7}$ reyns. Or Absolute vis. $\mu = 0.145 \times 17.2$, $\mu = 2.49$ micro-reyns (from equation 6).

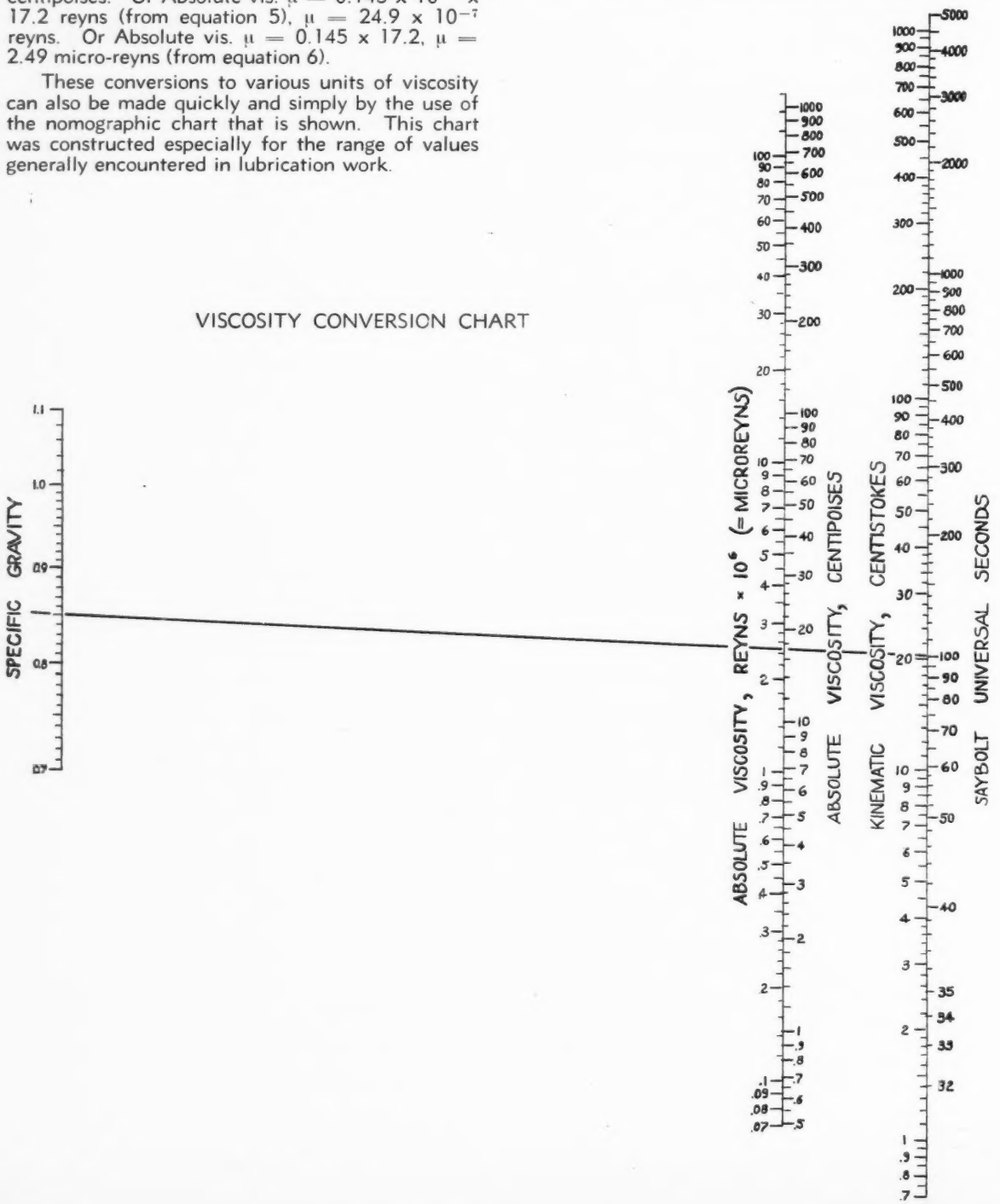
These conversions to various units of viscosity can also be made quickly and simply by the use of the nomographic chart that is shown. This chart was constructed especially for the range of values generally encountered in lubrication work.

For the same example of an oil with a viscosity of 100 Saybolt Universal Seconds and a specific gravity of 0.85, draw a straight line between these points located on the proper scales. It will be seen that in units of kinematic viscosity, the viscosity of this oil would be 20.2 centistokes and in units of absolute viscosity 17.2 centipoises, 2.49 microreyns or 2.49×10^{-6} reyns.

REFERENCE

[1]W. H. Herschel: Standardization of the Saybolt Universal Viscometer. Bur. of Standards Technical Paper 112, 1919, 25 pp.

VISCOSITY CONVERSION CHART



MECHANISMS OF SLEEVE BEARING FAILURE*

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INTRODUCTION: When bearings are considered as metallurgical structures rather than as machine parts, the actual mechanisms of their failure turn out to be relatively few in number, in spite of the numerous and diverse causes of bearing trouble. Because each of these basic mechanisms of failure produces characteristic features in the appearance of distressed bearings, it is often possible to deduce them by careful examination. This examination is frequently complicated by the simultaneous action of two or more destructive factors. However, with a knowledge of the effects of stress, dirt, heat, and corrosion, the most significant mechanism in any given bearing problem can usually be determined. Although a complete diagnosis usually depends upon analysis of the overall pattern of the failure and pertinent service information, determination of the failure mechanism by examination of damaged bearings is a necessary step.

It is the purpose of this paper to present an examination scheme for finding the most probable failure mechanisms of damaged bearings. The examination is made with the help of a wide angled magnifier and a magnetized pick or probe. The significant features of the most common bearing failures are shown and explained in the following discussion.

Whenever possible, every effort should be made to select, for examination, bearings which are representative of different stages in the failure. "Burned out" bearings are usually of little help because they all tend to look alike regardless of the mechanism of failure. However, a relative appraisal of the severity of the damage to different bearings in the same machine may be helpful in arriving at the cause of trouble, particularly when it is of a mechanical nature.

GENERAL FAILURE MECHANISMS: The principal causes of bearing distress—dirt, stress, heat, and corrosion—each produce disintegration of metallurgical structures by characteristic mechanisms. The general failure mechanisms that will be considered are: (1) Deformation, (2) Rupture, (3) Abrasion, (4) Corrosion, (5) Melting.

Because of interaction of the responsible factors, more than one of the above mechanisms may be involved in a single bearing failure. For example, high bearing temperatures are frequently responsible for failures by deformation, cracking, and corrosion, but are seldom high enough for actual melting. Excessive temperatures, on the other hand, are almost always encountered in the final phases of bearing failure regardless of cause. Also, it should be noted that many forms of damage to bearings increase localized loads or weaken the structure to promote cracking.

DEFORMATION: The characteristic result of bearing deformation is extrusion of the bearing alloy into the oil grooves and out of the ends of the sleeve. Extrusion may result from journal loads which are too high for the bearing either because of poor design or weakening of the bearing alloy usually by excessive temperatures. It is frequently associated with seizure and other types of failure. Since it is readily recognized, it will not be described further.

A special mechanism of failure involving deformation is seizure usually caused by lack of lubrication. Seizure is the result of bearing metal sticking to the journal so that it is torn out of the structure by shaft rotation. Severe cases can be recognized by the torn and distorted appearance of the bearing surface, and incipient cases by the characteristic scuffing marks which are scratches starting at points from which pieces of the bearing have been torn. Both these features are illustrated.

RUPTURE: Failure by cracking or spalling is the result either of bond failure, fatigue, or fracture of a brittle structure.

Bond failure is caused by improper application of the lining metal to the bearing and is characterized by complete and clean separation along the bond as shown. The unsupported lining breaks up into relatively large pieces and may be still ductile. Conclusive verification of the lack of soft bearing metal on the exposed backing may be obtained by scratching with a steel probe.

Fatigue is caused by alternating stresses which are below the ultimate strength of the structure but which are sufficient to cause the formation and progressive propagation of cracks from points of stress concentration. In backed bearings, cracks start at the surface, progress downward almost to the bond layer, and then run just above and parallel to the bond. In time, networks of cracks allow pieces of the bearing metal to be lifted out of the structure; these often are pressed into and smeared over the bearing surface. The pieces of metal thus spalled out are generally smaller than those broken out by bond failure.

Premature fatigue is caused either by excessively high stresses or by weak or weakened bearing structures, but fatigue also is the normal mode of failure for bearings which have given a good ser-

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vice life under normal conditions. Recognition of fatigue depends upon the detection of the characteristic crack networks and the thin layer of lining metal left on the backing after spalling. Heating or flexing the bearing will help reveal fine cracks by driving out the oil entrapped in them.

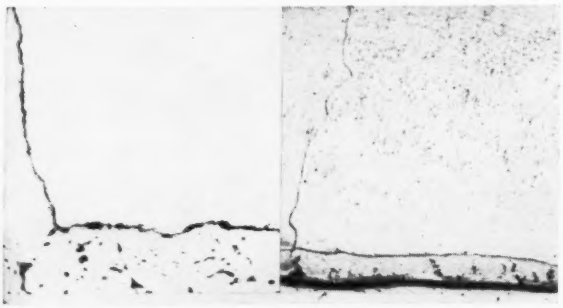

Fig. 1 (left) White material at top is babbitt lining applied to leaded bronze backing below. Crack runs down through the babbitt and then along the bond interface. (X75)

Fig. 2 (right) Bond layer between babbitt at top and bronze backing below appears as a broad dark line because it was not in focus when photographed. Fatigue cracks run down through the bearing metal and then along, but definitely above, the bond layer. (X75)

Selective removal of one of the microconstituents of a bearing by preferential melting or corrosion will generally weaken and embrittle the structure so that it finally fails by cracking. This is often observed in copper-lead bearings from which the lead has been removed. Somewhat similar cracking may also result from undesirable contaminants in bearing alloys which render them brittle. Cracking from these causes cannot always be distinguished from fatigue, with which it is closely related. However, crack networks are usually absent and the portions of the structure removed are frequently shallower than those removed by fatigue.

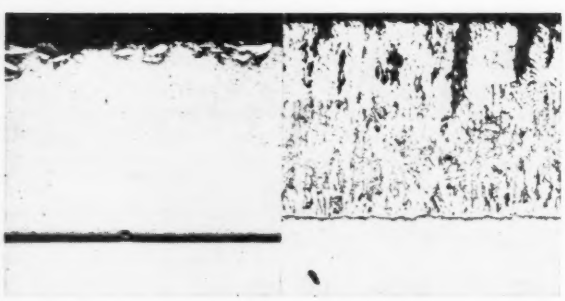

Fig. 3 (left) Many small white particles in the top of the speckled gray babbitt layer are pieces of steel embedded in the bearing surface. (X75)

Fig. 4 (right) Copper-lead alloy consists of white copper grains and speckled gray lead areas; steel backing below. Black areas in top of structure are voids left by corrosive lead removal. (X150)

ABRASION: The characteristic effect of abrasion is the circumferential scratches caused by the cutting of the bearing structure by hard particles. If the abrasive particles are fine, these scratches are not readily apparent, but enough material may be embedded in the bearing surface to give it a distinctly rough appearance and gritty feel. The embedment of abrasive particles is just as destructive as simple cutting of the bearing since a dirty bearing is, in effect, a charged lap and will cause wear of the journal and heating of the bearing. Because of these and other effects, dirt in bearings may cause fatigue and overheating (melting or corrosion) as well as simple abrasion.

Because there are some contaminating particles embedded in almost any bearing, it is a question of judgment as to when abnormally or harmfully dirty conditions are indicated. Generally speaking, if the bearings are definitely altered in appearance by either scratching or embedment of foreign particles, operating conditions may be considered to be excessively dirty. Sometimes over half the bearing surface may consist of abrasive material as illustrated in the accompanying photomicrograph.

It is possibly by careful probing with a pick to make a rough analysis of the foreign particles embedded in a bearing. The first classification is between metal particles and non-metallic minerals. Non-metallic minerals are usually the result of air borne contamination, but metal particles may originate within the machine. Iron alloys may be identified by their magnetism, and copper, brass, and, with some practice, aluminum by color. Care should be taken not to become confused by particles of re-embedded bearing metal.

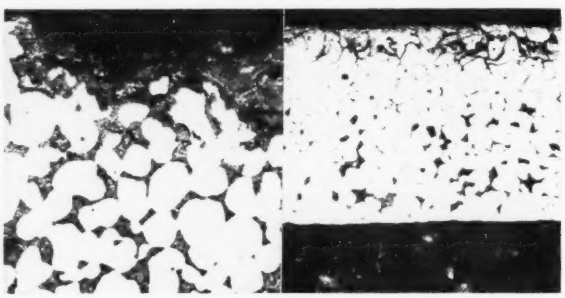

Fig. 5 (left) A pit has formed in the top of the bearing which is filled with sulfide deposit. Copper grains have been attached but lead has resisted corrosion. (X250)

Fig. 6 (right) Etched. Lead has been removed from upper portion of structure to leave practically solid copper grains which has been compacted and annealed by heat and pressure developed by seizure. Top layer is cracking from surface. (X150)

CORROSION: Corrosion may be considered as conversion of metal to metallic compounds. In order to become serious, the products of corrosion must be soluble, porous, or else be continually removed to expose fresh metal to attack. Corrosion is often selective in its action and attacks some constituents of an alloy faster than others, as in the case of the removal of lead from copper-lead bearings. The corrosive agents, in this case, are generally either compounds formed by oil deterioration or certain organic acids. A photomicrograph of a typical corroded bearing, from which the lead has been removed, is shown.

The visual indications of lead-corrosion in copper-lead bearings are somewhat ambiguous and in most instances a certain diagnosis can only be made microscopically. The photographs shown to illustrate this condition were taken of very badly

damaged bearings that were characteristic in their appearance. Such good examples are uncommon in practice. Very frequently, a bearing from which the lead has been removed will have a distinctly red color as compared to the bronze or brown-red color of an uncorroded bearing. A better indication of corrosion is the scratch test. A clean shallow scratch made by a sharp steel pick will be either silvery, bright red, or dull red. A silvery scratch indicates that the lead portion of the structure is intact and that none has been lost by either corrosion or sweating. Red scratches indicate lead loss. Generally if the scratch is a bright shiny red, the bearing has lost lead by sweating. If the scratch is dull and lustreless and oozes oil under the pressure of the probe, it is likely that the lead in the bearing was corroded. However, a clear distinction can only be made by metallographic examination and even then, not all cases can be resolved. Recently, radiographic inspection has been used to advantage in classifying doubtful cases.

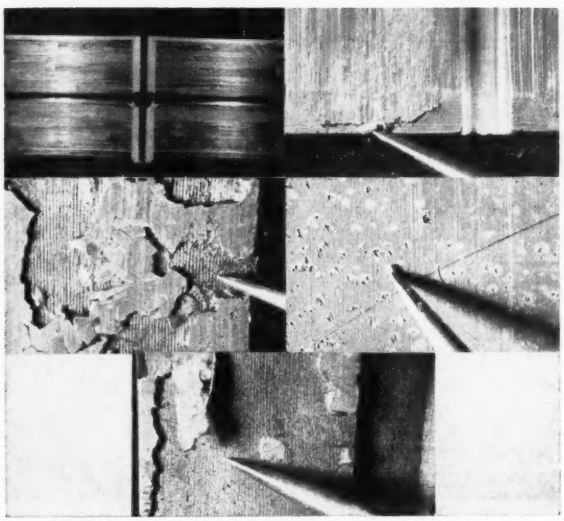

Plate A Top left: Surface of seized bearing is severely deformed and distorted (X2/5); Top right: Scuffing marks caused by the pick up of bearing alloy on the journal are visible at left. Bearing metal has been carried into oil distribution pocket (X2); Middle left: Relatively small areas spalled to leave a thin layer of soft bearing metal still on the backing. Crack networks are visible in remaining lining metal (X2); Middle right: Particles have caused scratches and sharp edged indentations surrounded by rounded bright areas. Magnetic probe shows when the particles, still embedded in the bearing, are steel or iron (X2); Bottom: Relatively large areas are spalled leaving no bearing metal on exposed backing. Bearing metal remaining has few crack networks and is still ductile (X2).

Another type of corrosion to which copper-lead bearings, as well as silver bearings, are subject is sulfide corrosion. This generally is the result of engine operation with high sulfur fuels. The characteristic feature of this form of corrosion is the black sulfide deposit formed on the bearing. This deposit is not soluble in the common organic solvents and so, can be distinguished from the varnish and resins frequently found on bearings. It is generally hard and brittle and is associated, in cases of severe corrosion, with pits in the bearing surface. In copper-lead bearings, the scratch test will be silvery indicating no selective loss of lead.

MELTING: When bearing temperatures are high enough, all or portions of the bearing will melt. When one constitutent of the alloy melts and oozes out of the structure, the bearing is said to have "sweated". Detection of masses of soft metal along the ends or near the low pressure areas of bearings is evidence of sweating. These masses usually have a rippled and flowed appearance. Sometimes, beads of "sweat" may be observed along oil grooves and at oil distribution pockets. In the case of copper-lead bearings which are also susceptible to lead corrosion, the differentiation between lead sweating and lead corrosion is sometimes only possible by microscopic examination. A sweated, copper-lead bearing usually has a burnished appearance caused by the high temperature to which it was subjected. Also, the back and the oil grooves of such a bearing are often blackened by varnish formed by decomposition of the lubricant. Frequently, sweating is accompanied by seizure. Scratches made in a sweated copper-lead bearing usually are reddish in color but have a bright lustre.

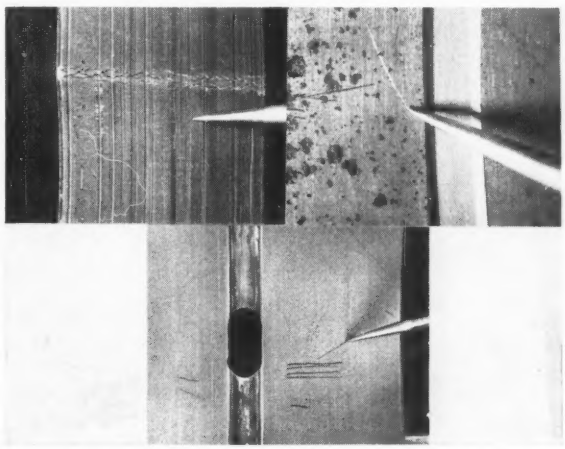

Plate B Top left: Bearing surface is scored and deformed. Scratch made by probe is red but shiny showing lead loss accompanied by copper compaction (X2); Top right: Hard black deposit fills pits in surface. Bearing overplate is largely unaffected. Bright silvery scratch made by probe indicates no selective lead removal (X2); Bottom: Small rounded pits visible in surface. Scratch made by probe is dull red and oozes oil (X3/4).

SUMMARY: The scheme of visual examination which has been described is somewhat oversimplified. In some cases, especially those involving more than one failure mechanism, it is impossible without microscopic examination to determine the most significant failure mechanism. However, even in complex cases, it is usually possible to eliminate one or more possible failure mechanisms which can be quite helpful in diagnosis.

It is believed that most bearing failures can be at least partially analyzed by the procedure described. However, there are, undoubtedly, several mechanisms which have not been included. One purposely omitted is cavitation erosion which has been increasingly encountered, particularly in connecting rod bearings of railway diesel locomotive engines and in the wrist pin bushings of certain other engines. The visible indications of this form of damage vary considerably and not enough experience has been gained, as yet, to identify the effects readily.

In utilizing the results of an analysis based

upon visual examination of damaged bearings, the causes of the several possible mechanisms should be remembered: (1) Deformation: stress, heat. Seizure: lack of lubrication. (2) Rupture. Bond failure: defective manufacture. Fatigue: stress, heat. Brittle cracking: sweating, corrosion, alloy impurities. (3) Abrasion: dirt. (4) Corrosion: heat, corrosive media. (5) Melting: heat.

Although the foregoing "causes" are perfectly general, they are the links necessary to connect the visual indications of failure with the design, lubrication, and operating factors which may be responsible for bearing trouble.

ACKNOWLEDGMENTS: The author wishes to express his indebtedness to Mr. Charles R. Schimpf, Metallographer, who prepared the microsections and the photographs included in this paper, and to Mr. Arthur C. Davis, Lubrication Engineer, who secured several of the bearing specimens required.

Personals

GEORGE L. SUMNER, Consulting Engineer for Westinghouse Electric Corp., East Pittsburgh, Pa., has announced his retirement as of July 1. The fourth President (1948) of ASLE, Mr. Sumner is a member of ASTM, Committee D-2, and Sectional Committee Z-11 of ASA on Petroleum Products & Lubricants.

New Officers on the Board of Directors of the C. A. Norgren Co., Englewood, Colo., include: C. N. NORGREN, Vice-President & Secretary; A. NIELSEN, Vice-President & Ass't. Treasurer; L. H. NORGREN, Treasurer & Ass't. Secretary; and F. R. POOL, Ass't. Secretary.

Precision Scientific Co., Chicago, Ill., has announced the appointments of C. A. WARNER, as Chairman of the Board; J. J. KINSELLA, President; A. PITANN, Vice-President & Secretary; G. E. BADER, Vice-President in Charge of Manufacturing; and E. E. TICE, Vice-President in Charge of Finances.

G. B. FUREY has been appointed Sales Engineer for Honan-Crane Corp., Lebanon, Ind., covering central and northwestern Indiana, including South Bend and Indianapolis.

New Officers for the Association of Iron & Steel Engineers include: E. L. ANDERSON, President; J. H. VOHR, 1st Vice-President; W. H. COLLISON, 2nd Vice-President; J. D. O'ROARK, Treasurer and L. LARSON, Secretary.

Reprints of REVIEW OF ASTM RESEARCH, as published in the December '52 and January & February '53 ASTM Bulletins, are available, without charge, from ASTM Headquarters, 1916 Race St., Phila. 3, Pa.

New Officers and Directors for the American Society of Civil Engineers include: D. V. TERRELL, President; E. R. NEEDLES (Zone 1) & M. G. LOCKWOOD (Zone 4), Vice-President; and Directors W. S. LaLONDE (Dist. 1), O. W. HARTWELL (Dist. 4), T. C. SHEDD (Dist. 8), S. B. MORRIS (Dist. 11), E. W. CARLTON (Dist. 14), and R. F. DAWSON (Dist. 15).

Obituaries: S. E. MURPHREE, Continental Oil Co., Ft. Worth, Tex., June 13; W. W. PITANN, Chairman of the Board and Founder of Precision Scientific Co., Chicago, August; J. W. SHEPHERDSON, Executive Vice-President (retired) of Morgan Construction Co., Worcester, Mass., Sept. 30.

Lubrication in the News

CHAIN OILING SYSTEM: Bulletin 69-30 just released, describes a new chain oiling system which lubricates one or more individual chains from a single reservoir. This single line system consists of a central oiler which feeds one or more valve brush assemblies (numerous brush sizes available for specific applications) connected in series by means of copper tubing; a combination of valve brush units can be used, each valve independently adjusted. For copies of bulletin, write: Oil-Rite Corp. (LE9/6), 2328 Waldo Blvd., Manitowoc, Wisc.

NON-METALLIC RUST INHIBITOR: A new rust inhibiting oil additive, identified as Atpet 100, is now available in commercial quantities for immediate indicated uses including: the protection of stored aircraft engines (both piston and jet), diesel and gasoline engines, turbines, pipe lines, and ferrous tools or components in production stages. A sorbitan mono fatty acid ester, it is shipped as a concentrate for addition by the refiner or compounder to his oil. Extensive testing shows: (1) protection considerably improved over kindred earlier inhibitors, even when used in reduced concentrations, and (2) consistently uniform protection. In a standard humidity cabinet test, it has withstood 634 hours' exposure at one percent concentration in oil. For samples and literature, write: Atlas Powder Co., Industrial Chemicals Dept. (LE9/6), Wilmington 99, Dela.

OILING & FILTERING SYSTEMS FOR PAPER MILL MACHINERY: As the speed and power of paper mill machinery has increased from year to year, the matter of bearing lubrication has become increasingly important until today bearing lubrication is the number one item of machinery maintenance. The Wm. W. Nugent Co., Inc., has issued a new Bulletin, No. 14B, describing their line oiling and filtering systems for paper mill machinery. Included are pressure type filters and gravity systems designed to assure an adequate supply of clean, cool oil to even the fastest, biggest paper mill machine. Copies may be obtained by writing: Wm. W. Nugent Co., Inc. (LE9/6), 401 N. Hermitage Ave., Chicago 22, Ill.

SELF-LUBRICATED BEARING MATERIAL: A new self-lubricating metal with exceptional bearing strength has been developed which may be used dry or in conjunction with oil. Employing both ferrous and non-ferrous metals, and specially formulated lubricative pigments locked together to create a self-lubricated metal, the ratio of lubricative pigment to metal can be rigidly controlled with maximum lubricity engineered to meet the requirements of specific bearing pressures. For further details, write: Booker-Cooper, Inc. (LE9/6), 8487 Melrose Pl., Los Angeles 46, Calif.

NON-FLAMMABLE HYDRAULIC FLUID: A new, non-flammable hydraulic fluid, "Houghto-Safe," has been developed that can be used in hydraulic equipment operated near open flames or adjacent to extreme heat conditions, combining maximum fire resistance with top hydraulic effi-

(Continued on page 323)

THE CRITICAL RAKE ANGLE METHOD OF EVALUATING CUTTING FLUIDS*

by W. E. Lauterbach, The Albright Co.
1316 W. Lake, Chicago, Ill.
E. A. Ratzel, Midwest Research Inst.
Kansas City, Mo.

INTRODUCTION: The Shell Oil Co. sponsored a program of research at Armour Research Foundation during the period from August, 1944, to December, 1948. The various experimental and analytical studies that were pursued during that time produced a wealth of information on the basic mechanics of the metal cutting process and, in particular, the role of the cutting fluid.

The critical rake angle (CRA) method of evaluating fluids was conceived during the first year of activity on the project from observations of chip formation and surface finish in the two-dimensional cutting operation (See Fig. 1). The method was explored extensively during the second year of study. It is the purpose of this paper to present the results of the studies conducted to show the application and limitations of the CRA method of evaluating cutting fluids and to substantiate the significance of the laboratory rating of a fluid.

EXPERIMENTAL ARRANGEMENT & EVALUATION PROCEDURE: The mechanical arrangement used in the laboratory for slow-speed planing is illustrated in Fig. 2. The arbor support of the milling machine was provided with a special attachment known as a variable rake angle tool holder. This device supported a standard 3/8-inch square by 3-inches long high-speed steel cutting tool and allowed the tool to be rotated in a vertical plane. Any rake angle in the range of 0 to 35 degrees could be set accurately in one degree intervals indicated by a protractor and indexing pin holes.

The work piece was a 3/16-inch thick plate held rigidly on its long edge relative to the bed of the mill and in the plane of the tool. A dial indicator was used to regulate precisely the depth of cut, the bed of the mill being elevated the desired amount. A test cut was accomplished by engaging the longitudinal feed of the mill.

Cutting fluid was applied from a funnel through Tygon tubing directly at the side of the tool thus assuring a copius supply in both the rake and clearance crevices. It was found that this technique assured that the cutting fluid passed under the cutting edge of the tool during chip formation[1]. A pan-like container surrounding the work piece served to recover the fluid used during a test cut, thus making possible the evalution of fluid samples as small as one quart.

A typical series of chip and work piece surface specimens are shown in Fig. 3. The chip photographs are direct while the surface photographs are copies from Fax-Film replicas. The rake angle was progressively increased from 10 to 23 degrees. Successive cuts were made on an SAE 1010 cold rolled steel plate, using Cutting Oil No. 33, at a depth of cut of 0.0050 inch, and at a cutting speed of 30 inches per minute.

The classifications given in Table I were used to designate variations in chip and work piece surfaces. Applying the criteria in Table I to the photographs of Fig. 3, the results obtained by varying the rake angle are as shown in Table II.

TABLE I

Surface	Type	Description
Chip	1	Brittle, discontinuous
	2	Ductile, continuous
Work Piece	A	Coarsely patterned
	A-a	Transitional
	a	Very finely patterned
	B	Not patterned

TABLE II

Rake Angle, degrees	Chip Surface	Work Piece Surface
10, 11	1	A
12	1	A-a
13, 14, 15, 17, 18, 19, 21	2	a
22, 23	2	B

TABLE III

Fluid Sample No.	CRA, deg	Sequence of Field Rating of Samples
X*3	5.0	5 (best)
5	8.0	6
6	10.5	7
7	10.5	11 and 10
11	11.0	8
33	11.5	33
10	12.0	9
8	12.5	12
X*2	12.5	4
4	13.0	17 (poorest)
12	14.5	
9	16.0	
X*1	17.0	
17	20.0	
Dry	26.0	

Table I (top) Chip and work piece surface classifications.

Table II (middle) Classifications applied to sample CRA test.

Table III (bottom) Laboratory and field evaluation of cutting fluids. Cutting Conditions: Actual depth of cut, 0.0050 ± 0.0002 in.; Cutting speed, 30 ± 0.5 in/min.; Tools, Mo-Max HSS, Tool angle = 55 deg.; Specimens, SAE X1025 CR, 3/16-in. thick. *Experimental fluids (Other laboratory tests had indicated that Oil No. 3 was the best oil among the several samples tested.)

The correspondence described in Table II between rake angle and combination of chip and surface finish is characteristic of cutting dry or with a fluid. When the experimental procedure was repeated for other oils, the sample physical occurrences were observed. However, the rake angles corresponding to particular types of chips and surfaces varied for different oils and materials. In many instances the changes occurred in a very narrow range of rake angles with direct transition from a Type A to Type B surface. The rake angle at which this transition phenomenon occurs is defined as the critical rake angle. It is established by averaging the values of adjacent rake angles at which Type I

*Sponsored by the ASLE Technical Committee on Fluids for Metal Working, and presented at the ASLE 8th Annual Meeting, Boston, April 14, 1953.

(discontinuous) and Type 2 (continuous), chips are observed to occur respectively with Type A surface and Type a surfaces. Based on this definition it is possible with some indoctrination to interpret consistently the laboratory results and to be confident of the comparison of one fluid to another.

TABLE IV

Fluid Sample No.	R, lb	M, deg	d, in. x 10^{-4}
X*3	340	75.5	36
5	375	70.0	41
33	365	72.5	40
9	385	71.5	44
Dry	375	72.5	45

TABLE V

Work Material	Actual Depth of Cut		CRA, degrees			
		Dry	No.9 Oil	No.33 Oil	No.5 Oil	No.X*3 Oil
SAE X1025CR	(a) 0.0050	26.0	16.0	11.5	8.0	5.0
SAE X1025 Annealed	(a) 0.0020	28.0	14.5	12.0	7.0	3.5
SS 304 Annealed	(b) 0.0050	8.5	0.5		-1.5	
	(b) 0.0100		3.0		3.0	
SAE 1112 CR	(a) 0.0050	13.0	8.5	4.5	≤0	
SAE 2340 Annealed	(a) 0.0050	12.5	≤0	7.5	5.5	
SAE 2340 Quenched and Drawn	(a) 0.0050	22.5	14.5	17.0	12.5	8.5
SAE 52100 Spheroidized Annealed	(a) 0.0050	31.0	29.0	29.0	28.5	26.5

Table IV (top) Tool force and the depth of cold work at the CRA. NOTE: R = Magnitude of resultant tool force; M = Direction of resultant tool force from vertical; d = Depth of cold work.

Cutting conditions for determining R and M: Planning on mill with tool force dynamometer; Actual depth of cut, 0.0050 ± 0.0002 in.; Cutting speed, 30 ± 0.5 in/min.; Tools, Mo-Max HSS, Clearance angle = 5 deg.; Specimen, SAE X1025 CR 3/16-in. thick.

Cutting conditions for determining d: Planning on mill with variable rake angle tool holder; Actual depth of cut, 0.0020 ± 0.0001 in.; Cutting speed, 30 ± 0.5 in/min.; Tools, Mo-Max HSS, tool angle = 55 deg.; Specimen, SAE X1025 Annealed 3/16-in. thick. *Experimental fluid.

Table V (bottom) CRA evaluations for various work materials and cutting fluids. (a) Tool angle = 55 degrees; (b) Clearance angle = 5 degrees. Cutting conditions: Cutting speed, 30 in/min.; Tools, Mo-Max HSS; Specimens, all 3/16-inch thick. *Experimental fluid.

IMPLICATIONS OF THE CRA METHOD: The first laboratory tests in which the CRA method was employed showed only that there were differences between cutting dry and with each of two fluids. Naturally, two questions arose: (1) Is the CRA of a given oil reproducible and is the sensitivity of the method within the limits of experimental variation? (2) Is the CRA of a given oil actually an indication of the effectiveness of the oil?

The first question was answered in the affirmative after studies were made on the CRA method as influenced by (1) cutting tool properties (rigidity, sharpness, included tool angle), (2) work piece properties (type of steel, width of cut, heat treatment), (3) cutting speed, and (4) depth of cut. The results of these tests suggested some refinements in the CRA procedure. Certain of these studies will be presented briefly later in this paper.

The second question was answered by two separate series of experiments.

The Shell Oil Company provided twelve cutting fluids which were evaluated by the CRA process. The oils and their CRA's were tabulated in order of increasing angle and compared to an independent empirical classification by field representatives in the order of "best" to "poorest". This data is given in Table III. As there is close agreement between the laboratory evaluation and the field rating, it is assumed that the method is a valid physical test.

To discover whether or not the CRA method had a definite correlation with the effectiveness of the oil, two techniques were employed. A tool force mechanical dynamometer was used to obtain the vertical and horizontal components of force when cutting with each of four cutting oils and dry cutting. The rake angle of the cutting tool was varied between the lower boundary of the CRA region and 36 degrees. All other cutting conditions were held constant.

Individual curves of tool force versus rake angle and other derived relations were obtained. The results show that the magnitude and direction of the resultant force are practically constant at the CRA of each oil and dry cutting. Table IV summarizes the experimental data.

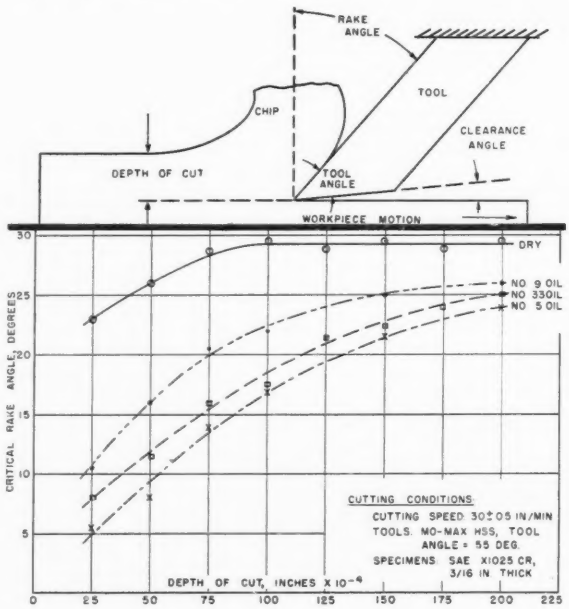

Fig. 1 (top) The two-dimensional cutting process.

Fig. 4 (bottom) The effect of depth of cut on CRA.

The second series of experiments was related to the determination of the depth of cold work or plastic flow in the work piece for dry cutting and for cutting with various fluids. The details of this work are presented in another paper[2] by the authors. Very briefly, the depth of cold work in annealed steel specimens was determined by x-ray diffraction. It was found that the depth of cold work is inversely proportional to the effectiveness of the oil; the smallest depth of cold work is found with the oil rated as most effective (by the independent field rating shown in Table I.) The depth of cold work increases with decreasing rake angle for a given cutting oil and other cutting conditions held constant.

The CRA's of several oils were found for these conditions. Although the angles differ from those found previously for the same oils evaluated with the cold rolled steel, the relative rating of these oils is the same.

Table IV also shows the depth of cold work at the CRA's of the several oils tested. These values are approximately constant.

It is concluded, therefore, that at the CRA some important characteristics assume definite numerical values, since they are a consequence of the mechanical behavior of the work material during the process of chip formation.

THE CRA METHOD AS AFFECTED BY CHANGES IN CUTTING CONDITIONS: The CRA method was explored extensively. Experimentation to study the behavior of the method when each of the independent variables (depth of cut, work material, and cutting speed) were varied led to a better understanding of the limitations of the procedure. These studies are presented briefly.

(A) THE EFFECT OF DEPTH OF CUT ON THE CRA: Critical rake angles for several oils and dry cutting were determined for depths of cut of 0.100, 0.125, 0.175 and 0.200 of an inch. The cutting speed, work material, and tool were held constant. The graphical compilation of CRA against depth of cut (see Fig. 4) indicates that the CRA becomes more and more independent of the depth of cut as the depth of cut is increased. This is particularly true for dry cutting, the CRA's of which are approximately constant for depth of cut between 0.100 and 0.200 inch. Oil curves continuously approach the dry cutting curve which is in agreement with the hypothesis that cutting oils become less effective as the depth of cut is increased.

It is seen that the CRA must be defined for a specific depth of cut. Based upon these results (and others which follow) a "standard" depth of cut of 0.0050 inch was adopted for the normal evaluation procedure.

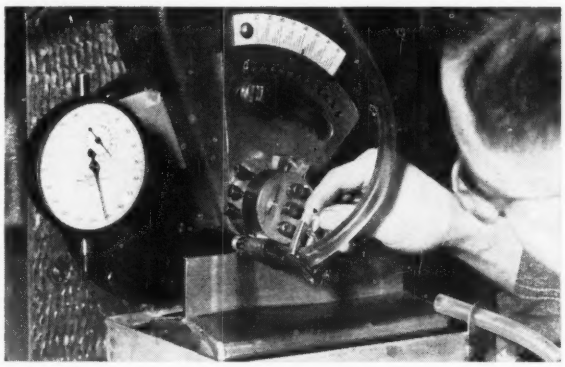

Fig. 2 Test set-up for slow-speed planing.

(B) THE EFFECT OF WORK MATERIAL AND ITS PHYSICAL PROPERTIES ON THE CRA: Ferrous work materials representing a wide range of physical properties were used. These include SAE X1025 annealed, SS 304 annealed, SAE 112 cold-rolled, SAE 2340 annealed, SAE 2340 quenched and drawn, and SAE 52100 spheroidized annealed. The cutting speed and tool were held constant and the CRA procedure was repeated for dry cutting and with Oils Nos. 9, 33, 5 and 3.

The test results are summarized in Table V. In general, the cutting oils have the same relative rating on each work material, although the actual CRA is different. The CRA range between dry cutting and with the "best" fluid, varies from 4.5 degrees on SAE 52100 to 24.5 degrees on SAE X1025 annealed. It was found that SAE X1025 cold-rolled has physical properties which produce the most sharply defined critical rake angles of the several work materials used in this test. This fact, plus the large CRA range from dry cutting to the best oil, and the very close reproducibility of results obtained on this material made it the best of the seven work materials for CRA evaluations.

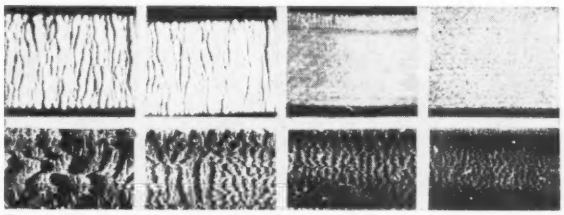

Fig. 3 Rake angle and surface finish. Top row: Appearance of chip (from left to right) Type 1, 11°; Type 1, 12°; Type 2, 13°; Type 2, 14°. Bottom row: Fax-Film record of work surface (from left to right) Type A, Type A-a, Type 2, Type 2.

(C) THE EFFECT OF CUTTING SPEED ON THE CRA: One of the most important of this series of experiments was the investigation to determine the limiting cutting speed, for various cutting conditions, imposed by the disappearance of the CRA. The use of the mill as a slow-speed planer was limited to cutting speeds under 100 inches per minute. A device was built to adapt a lathe to high speed, two-dimensional cutting above 100 inches per minute. Briefly, the work material (in plate form) was bolted to the face of a large block of steel held in the chuck, the face of the block having been formed to assure rotation of the edge of the work material as a segment of screw with a square thread. The longitudinal feed of the cutting tool was indexed to the rotation of the work material. Thus, a continuous cut on the edge of the work material was accomplished. This action simulated the planing action in the former tests. Tests were performed for dry cutting and with Oil No. 33 at a depth of cut of 0.0050 inch. It was found that the limiting speed was 225 inches per minute and 200 inches per minute for these two conditions, respectively, as for those speeds, the CRA's are either zero or negative. This means that the CRA method is limited to low cutting speeds.

REFERENCES

[1]W. E. Lauterbach & E. A. Ratzel: An Investigation Into The Flow & Effect Of A Cutting Oil In Machining Operations. Lubrication Engineering, Vol. 7, No. 1, pp. 15-19.

[2]W. E. Lauterbach & E. A. Ratzel: Evaluating Cutting Oils By Determining Their Effectiveness In Reducing Sub-Surface Grain Distortion. Lubrication Engineering, Vol. 8, No. 5, pp. 238-240, 261-262.

ACKNOWLEDGMENTS: Grateful acknowledgment is made to Mr. Seichi Okubo of Armour Research Foundation and Mr. Richard Gieselman, formerly of the Foundation, for their able assistance in conducting parts of this investigation. The authors are particularly grateful to Dr. C. O. Dohrenwend, formerly of Armour Research Foundation (now Dean of Engineering, Renselaer Univ.), for his assistance, advice, and inspiration.

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THE FOIL BEARING— A New Departure In Hydrodynamic Lubrication*

by H. Blok, Technical University
Delft, Holland
J. J. vanRossum, Royal Dutch/Shell Lab.
Delft, Holland

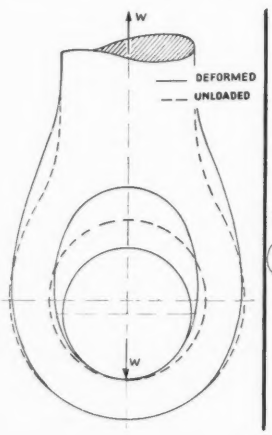
NOMENCLATURE

f	coefficient of friction
h_0	thickness of the oil film between foil and journal
h_{min}	minimum thickness of the oil film
N	rotational speed of journal
p	pressure
p_m	mean pressure per unit of projected bearing area
R	radius of journal
ΔR	radial clearance in a classical bearing
r	radius of curvature
σ	tensional force in the foil per unit of width
Z	viscosity
ZN/p_m	dimensionless parameter
U	peripheral speed of journal

INTRODUCTION: In a journal bearing running in the region of hydrodynamic lubrication, the load is borne by the pressures developed in the oil wedge that establishes itself between the surface of the journal and that of the bearing. Assuming the journal to be absolutely rigid, one can distinguish two limiting cases: (1) The bearing is likewise completely rigid. The classical bearing with which the classical theory of hydrodynamic lubrication concerns itself, is a case in point. (2) The bearing is entirely devoid of rigidity. An example is a bearing consisting of an extremely flexible foil, stretched around half the circumference of the journal. This bearing has been termed "foil bearing."

Intermediate between these limiting cases are those in which the rubbing surfaces are prone to deformation caused, either by the pressures in the oil wedge or by the external forces acting on the bearing. These deformations are of two kinds, viz.: (a) The deformations in the immediate neighbourhood of that section where the film thickness attains its minimum. They are caused by the hydrodynamic pressures, which there reach their maximum. There is an interaction between generation of hydrodynamic pressures and the elastic deformations of the surfaces. The study of this interaction is primarily of interest in relation to the lubrication of gears in which the oil pressures are of the order of the contact pressures calculated according to Hertz[1,2]. (b) Deformations of the bearing as a whole, caused by external forces that introduce circumferential bending moments into the bearing shell. Bearings are more susceptible than gears to this sort of deformation[3,4]. By way of example, Fig. 1 shows a big-end bearing with the bending deformation greatly exaggerated. In this example, the deformation causes lengthening of the active part of the oil wedge, and this promotes the hydrodynamic performance of the bearing.

The foil bearing may be considered as a bearing that offers no resistance at all to deformation. This limiting case has been realized by means of a model in which a very thin cellophane foil is stretched round a journal and loaded as in Fig. 2. From experiments with this model it has been found that the pressure and the thickness of the film separating the foil from the journal are constant except for the leading and trailing portions of the film. The foil thus causes an oil film to form that has parallel surfaces, along the whole length of which, remarkably enough, the pressure is constant. Although the classical theory of Osborne Reynolds states that such a film is possible in the case that the surfaces are parallel, with rigid surfaces this can be realized only if the pressure is maintained artificially at the trailing portion of the film, for instance by introducing oil under pressure[5].



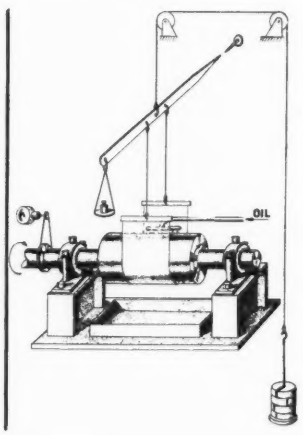


Fig. 1 (left) Flexure of a big-end bearing.

Fig. 2 (right) Sketch of a model foil bearing.

EXPERIMENTS: Friction on the foil has been measured by means of a model, using the set-up shown in Fig. 2. An electric motor drives a journal 6 cm (2.35 in.) in diameter, round which is a cellophane foil stretched by the load (see Fig. 2). The foil is 20 cm long (7.88 in.), 0.008 cm thick, (about 3 thous.) and 8 cm (3.15 in.) wide (4 cm, that is 1.58 in., in some experiments). The speed of the journal was varied between 6 and 1500 rpm, the load between 1 and 27 kg (2.2 and 60 lbs), and the viscosity of the oil between 6.5 and 100 centi-

*Paper presented before the Symposium on Engineering Studies of Bearings, organized by the Assoc. for the Advancement of Mechanical Engineering, Paris, June 23, 1952; republished by courtesy of Ingenieurs et Techniciens, see No. 51, 1953, 29/32.

poises. This means a large variation in the lubrication number ZN/p_m although the load P itself was kept rather low.

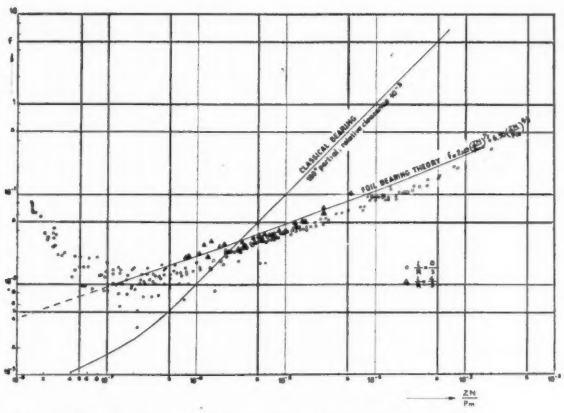


Fig. 3 Coefficient of friction as a function of ZN/p_m.

Fig. 3 shows the coefficients of friction, f, found in the experiments as a function of the dimensionless parameter ZN/p_m (Z = viscosity in Poises, N = speed in revs. per sec., and p_m = specific pressure in dynes per sq. cm). Because this parameter is dimensionless, its value is independent of the system of units employed, as long as one chooses a consistent system. One such consistent system is that where Z is expressed in lb sec/sq. in., N in revs./sec., and p_m in lb/sq. in.

It is seen from Fig. 3 that the results for foils 8 cm and 4 cm wide follow the same curve. The greater part of the curve for 8 cm width corresponds to the curve calculated in Appendix II for a foil of infinite width, that is to say, one without side leakage. By mixing powdered aluminum with the oil, it was possible to observe, through the transparent foil, the flow of the oil and to verify that the side leakage is indeed very slight.

The theoretical curve was worked out by assuming constant thickness of the film of oil between the journal and the foil. The agreement between the experimental results and this curve makes this hypothesis appear acceptable. (The mechanism of the hydrodynamic formation of the parallel film may perhaps apply to belt drives. We draw attention to the fact that the coefficient of friction of a belt and pulley increases with the speed, as does the coefficient of friction of the foil bearing (M. Auclair, 1922: Essai d'une theorie du fonctionnement des courroies; Memoires Soc. Ing. Civils de France 1922, 496/523).). Moreover, it proved possible to corroborate the hypothesis by the following, totally different method.

The foil is considered as being wholly devoid of bending rigidity. For a small element of the foil (see Fig. 4) the equilibrium between the hydrodynamic pressure p in the oil film and the tension σ in the foil can be expressed by, (1): $2\,\sigma \cdot \sin(\frac{1}{2} d\Phi) = p\,r\,d\Phi$, ignoring the influence of the differential $d\sigma$ of the tension caused by friction. One may write $\sin(\frac{1}{2} d\Phi) = \frac{1}{2} d\Phi$ and consequently, (2): $p = \sigma/r$.

If one measures the local radius of curvature the local pressure can be deduced from it with the aid of relationship (2). An optical method was used for measuring r: The outer surface of the foil was covered with a thin layer of aluminum so as to form a convex mirror in which a lighted screen was reflected. From the height of the image of the screen seen in the reflecting foil it is easy to calculate the radius of curvature. Fig. 5 shows the arrangement used, which was calibrated by means of polished cylinders, of different diameters and very accurately machined.

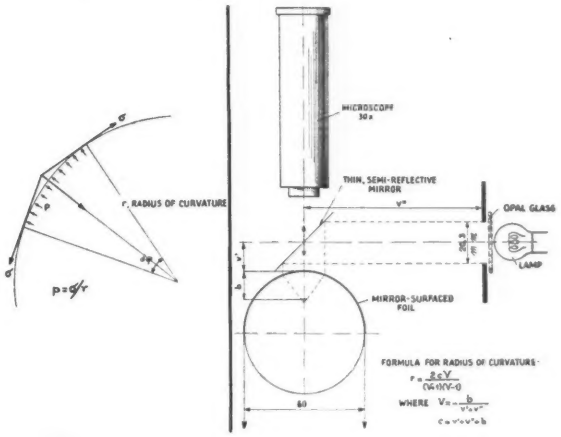


Fig. 4 (left) Foil element.

Fig. 5 (right) Set-up for measuring radiuses of curvature.

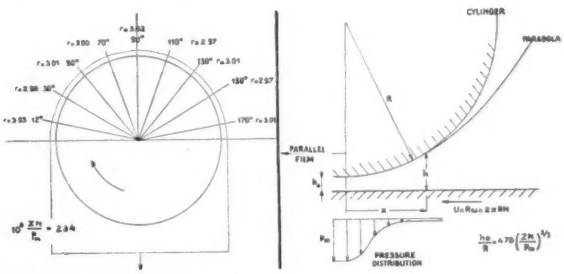


Fig. 6 (left) Measured radiuses of curvature.

Fig. 7 (right) Intake of the parallel film.

As an example, Fig. 6 gives the radiuses of curvature measured at the median plane of the active foil area for a value of the dimensionless parameter $10^8 ZN/p_m = 234$. Although this method permits measuring the radius of curvature to an accuracy of 1-2 per cent, it is not sufficiently accurate for deducing the thickness of the oil film. The latter, according to the theory expounded in Appendix I, is of the order of 0.0025 mm (a tenth of a thou) at $ZN/p_m = 234$. Making use of Equation (2), one may thus draw the conclusion that, as far as concerns the active part of the foil bearing, the hydrodynamic pressure in the oil film has been constant to within a few per cent, and that consequently the thickness of the oil film will have shown a similar constancy. Because of edge effects, which are not accounted for by the foregoing equations, this conclusion should break down at the sides of the foil. However, on the ground of what has been said about smallness of side-leakage, it is thought that the edge effects (except at the very edges) do not disturb the constancy of film thickness to any appreciable extent.

DISCUSSION OF RESULTS: In Appendix I

To determine the relative performance characteristics of five competing open gear lubricants, a major steel producer established the 4-Gram Test . . . an experiment which reproduces as closely as possible service conditions encountered in open gear lubrication.

In this experiment the Timken Testing Procedure was modified slightly to reproduce more precisely actual service conditions. Flow of lubricant to the hardened and ground steel block and cup was cut off, and 4 grams of the lubricant being tested were applied at room temperature. The machine then was set in motion and watched closely for signs of scoring.

Five lubricants, all accepted by industry as "good quality," were tested. Results showed *that LEADOLENE KLINGFAST gave over 3½ times the service of the next best lubricant and up to 6 times the service of the other lubricants tested.*

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Results
OF 4-GRAM TEST

LEADOLENE KLINGFAST—30 minutes—without scoring or failing.

LUBRICANT "A"—5 minutes—a high grade compound scored at 5 minutes and failed in 12 minutes.

LUBRICANT "B"—8 minutes—a reputable lubricant of residual nature scored and failed in 8 minutes.

LUBRICANT "C"—6 minutes—a good lead compounded extreme pressure lubricant scored and failed in 6 minutes.

LUBRICANT "D"—6 minutes—a lead-compounded lubricant scored and failed in 6 minutes.

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a calculation is made of the thickness h_o of the oil film between the journal and the foil, and it is found that, for the ratio of this thickness to the radius R of the journal, (3) : $h_o/R = 4.78\ (ZN/p_m)^{2/3}$.

Here p_m represents the specific pressure for which may be written: $p_m \cong \sigma/R$.

Formula (3) is valid for relatively small values of h_0, say for: $h_0/R < 10^{-2}$ or $10^8\ ZN/p_m < 10^4$.

For the purpose of comparing the operational reliability of the foil bearing with that of the classical bearing, the following expression (Expression (4) was derived from that given by Martin[5] for gears: $h_{min}/r = 2.45\ ZU/W$. In our case the peripheral speed $U = 2\pi RN$ and the load per unit of width $W = 2Rp_m$, whilst $1/r = 1/R - 1/(R+\triangle R) \cong \triangle R/R^2$ if $\triangle R/R$, the clearance ratio, is sufficiently small.) is given for the minimum film thickness, h_{min} valid for the classical bearing at low values of ZN/p_m, (4) : $h_{min}/R = 7.70\ (R/\triangle R).\ (ZN/p_m)$.

The two formulas (3) & (4) enable us to compare the minimum film thicknesses of the two bearings at high loads. To this end the ratio h_o/h_{min} is determined and it is found that: $h_o/h_{min} > 1$ for $ZN/_{pm} < 0.24\ (\triangle R/R)^3$.

It follows that for a clearance ratio $\triangle R/R$ of say 10^{-3} under operating conditions, the foil bearing gives a greater film thickness (and thus greater operational reliability) than the classical bearing only when $10^8\ ZN/p_m < 0.024$, which is below the values considered acceptable if the bearing is to run properly. From this point of view, then, the foil bearing has no advantage over the classical bearing. Nevertheless there is at least one case in which the foil bearing would appear to provide a solution to the problems encountered when the classical bearing is used, and that is, where a bearing is to operate at high temperatures. In such a case the designer has to contrive a bearing with relatively large clearance so as to allow for the different thermal expansions of the journal and the bearing. Here he is still far from being able to make exact calculations, and he can only estimate the clearance in a rough-and-ready kind of way. The very real risk that the journal and bearing will bind remains present. The foil bearing, however, itself regulates the clearance so that there is no risk of binding of the journal.

APPENDIX I Calculation of the film thickness of a foil bearing. The film of oil separating the foil from the journal consists of the following three parts: (1) The parallel part, extending over half the circumference of the journal, (2) The leading part, at the intake to the parallel part, (3) The trailing part, at the outflow of the parallel part.

Our starting point is Reynolds' equation (By means of Equation (2), in which one can write: $1/r = 1/R - (1/R^2)\ .\ d^2h/d\Phi^2$, if h/R and $(1/R^2)\ .\ dh/d\Phi$ are sufficiently small, Reynolds' equation permits the establishment of the differential equation that expresses film thickness, h, as a function of Φ. It is found that: $-(\sigma/R^3)\ .\ d^3h/d\Phi^3 = 6\ ZU\ .\ (h^* - h)/h^3$. It is readily seen that the solution which has been found experimentally, that is, $h = h^* = h_o$ (constant) satisfies the last equation.), (5): $dp/dx = 6\ Z\ U\ .\ (h^* - h)/h^3$.

This equation is valid for all three parts of the film. For the parallel film $h = h^* = h_o$

and consequently $dp/dx = 0$, hence pressure p is constant.

As long as flow in all three parts of the oil film is considered to be two-dimensional (no side-leakage or sideways contraction in any part of the film), oil flow in the peripheral direction, or say h^* in Equation (5), cannot but be constant throughout the entire film. However, the assumption that h^* equals h_0, the uniform thickness of the parallel part of the oil film, can be shown to be untenable for the two-dimensional flow postulated.

It is thought that this assumption is nevertheless essentially correct, but that in the leading and trailing parts of the film oil flow is not two-dimensional, in contra-distinction to the oil flow in the parallel part. In fact, in the leading part some side-leakage did occur, whilst in the trailing part there was a contraction in that the oil film broke up into a row of narrow streams of oil, interspersed with air spaces, and parallel to each other in the peripheral direction. These phenomena must be taken into account, it is thought, if one is to arrive at a full explanation of the curious fact that in a foil bearing the pressure in the parallel part remains uniform, whereas in a rigid bearing having the same geometry of oil film the pressure in the part considered falls off rather steeply towards the trailing part.

To calculate the thickness consider the leading part, where the hydrodynamic pressure is developed (see Fig. 7).

For sufficiently low values of h_0, say for $h_0/R < 10^{-2}$, the pressure is generated mainly in the region immediately before the beginning of the parallel film, and the oil wedge formed between a plane surface and a cylinder may be replaced by a parabolic wedge. Therefore, as in Martin's theory, write (6): $h = h_0 + (x^2/2R)$.

Equation (5) can be integrated by substituting $x^2/2\,Rh_0 = tg^2\psi$, as was done by Martin. Then it is found that (7): $p/ZN = -(3\pi/\sqrt{2}) \cdot (R/h_0)^{3/2} \cdot (\psi - \frac{1}{4}\sin 4\psi) + C$.

Given the following conditions: $p = 0$, for $x =$ or $\psi = \pi/2$, and $p = p_m$, for $x = 0$ or $\psi = 0$, the thickness ratio h_0/R is found to be (8): $h_0/R = 4.78\,(ZN/p_m)^{2/3}$.

APPENDIX II Calculation of the coefficient of friction of a foil bearing. Throughout the parallel part of the film the pressure is constant, and consequently the distribution of the speeds of flow is the same for all film sections. This distribution is linear across the film, just as in a Couette viscometer[7]. For the parallel part the friction exerted on the foil may be written (9): $F_1 = 2\pi^2 ZNR \cdot R/h_0$.

In the other two parts, the distribution of speeds is the result of two flows[8,9]: 1. Couette-type flow, with a linear speed-variation, across the film; 2. Poiseuille-type flow, caused by the pressure-variation along the film. The resulting distribution of speeds is parabolic. While the friction generated by this Poiseuille-type flow drags the foil along in the trailing part, in the leading part it restrains it with an equal force. This Poiseuille-type flow therefore does not contribute anything to the total friction.

The friction due to Couette-type flow in the leading part adds up to that in the trailing part, and the sum of their contributions to the total frictional force may be written:

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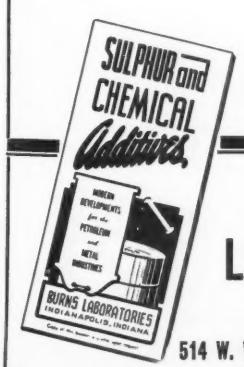

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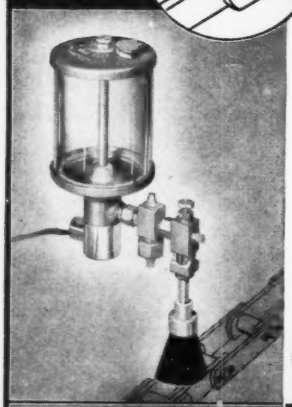

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By making use of (6) and integrating, it is found that (10): $F_2 = 2\pi^2\sqrt{2}\,ZR\,.\,(R/h_o)^{1/2}$.

The summation of F_1 and F_2 gives the total friction F on the foil. Making use of (8) for the coefficient of friction $f = F/2p_mR$ may be written (11): $f = 2.05\,(ZN/p_m)^{1/3} + 6.30\,(ZN/p_m)^{2/3}$.

For $10^8\ ZN/p_m < 10^4$ the second term represents a correction of less than 4 per cent on the first term and may be ignored. One thus sees that in this region of ZN/p_m the coefficient of friction increases less rapidly with ZN/p_m for the foil bearing than for the classical bearing in which, in the region considered, the coefficient of friction is proportional to $(ZN/p_m)^{1/2}$.

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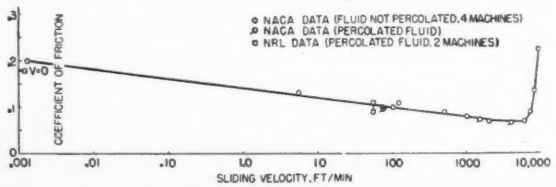
(Lube Lines, Continued from page 293)

quirements for technical information from the simplest data to comprehensive reports on the current state of knowledge on materials, processes or products. Technical literature contains data relevant to practically every research problem in which a company may be interested, whether it be development of new products, improvement of existing products, or reduction of costs through new or substitute materials or other means.

SUPPLEMENT to June, 1953, LE, p, 172: For immediate reference, the following illustration should accompany the Authors' Closure of the paper The Lubrication Characteristics Of Synthetic Lubricants At High Sliding Velocities, by R. L. Johnson, M. A. Swikert, and E. E. Bisson. Though the content of the illustration is indicated in the key, reference should be made the original paper for complete details.



Key: Effect of purity of Di(2-ethyhexyl) sebacate on friction coefficient as obtained in 6 different pieces of evaluation apparatus. (Fluid purification obtained by percolation through absorption columns.) Load range, NACA studies, 200 to 2400 grams; NRL studies, up to 20,000 grams. Speciments, in all cases, steel on steel.

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Air Bearings—Low Friction, by D. D. Fuller 9-6
Cleaning Lubrication Systems, by A. S. Morrow 9-1,10
Contamination Of Surface Waters By Waste Oils, by D. E. Bloodgood 9-2, 81
Cooling & Lubrication Of High Speed Cylindrical Roller Bearings, by W. J. Anderson & E. F. Macks 9-5,263
Critical Rake Angle Method Of Evaluating Cutting Fluids, The, by W. E. Lauterbach & E. A. Ratzel 9-6
Development Of Significant Bench Tests For Aircraft Turbine Lubricants, The, by E. A. Ryder 9-4, 201
Effects Of Modern Design Trends On Ball Bearing Research, by L. D. Cobb 9-2, 78
Electrographic Spot Testing Of Bearing Surfaces, by A. E. Roach & A. O. DeHart 9-6
Evaluation Of Drawing Lubricants, by W. J. Wojtowicz. 9-1, 19
Evaluation Of Lubricants For Use In Computing Machines, The, by L. J. Hibbert & R. F. McKibben 9-1, 16
Fatigue Spin Rig—A New Apparatus For Rapidly Evaluating Materials & Lubricants For Rolling Contact, The, by E. F. Macks 9-5, 254
Foil Bearing—A New Departure In Hydrodynamic Lubrication, The, by H. Blok & J. J. vanRossum 9-6
Friction & Boundary Lubrication, by A. C. West 9-4, 211
Frictional Behavior Of Polyethylene, Polytetrafluoroethylene & Halogenated Derivatives, by R. C. Bowers, W. C. Clinton & W. A. Zisman 9-4, 204
Hydraulic Equipment Builder's Viewpoint (Progress Report: JIC Hydraulic Standards, Part 1), by J. Robinson 9-1, 22
Industrial Equipment User's Viewpoint (Progress Report: JIC Hydraulic Standards, Part III), by A. McHugh 9-1, 26
Influence Of Solid Surface Films On The Friction & Surface Damage Of Steel At High Sliding Velocities, The, by E. E. Bisson 9-2, 75
Lubricating Greases, by J. L. Finkelmann 9-3, 127
Lubrication Characteristics Of Synthetic Lubricants At High Sliding Velocities, The, by R. L. Johnson, M. A. Swikert & E. E. Bisson 9-3, 144
Lubrication Requirements Of Gears As Seen By A Gear Engineer, by L. J. Collins 9-5, 246
Machine Tool Builder's Viewpoint (Progress Report: JIC Hydraulic Standards, Part II), by K. O. Tech 9-1, 24
Mathematical Symbols For Lubrication Problems, by J. Boyd 9-4, 209
Mechanism Of Fretting, The, by I-Ming Feng & B. G. Rightmire 9-3, 134
Mechanisms Of Sleeve Bearing Failure, by P. B. Burgess ... 9-6
Minimum Oil Requirements Of Ball Bearings, by E. R. Booser & D. F. Wilcock 9-3, 140
New Performance Test For Cutting Fluids A, by J. M. Stokely 9-3, 137
Open Gear Lubrication, by H. W. Winkler 9-6
Recommended Practices For The Cleaning Of Turbine Lubricating Systems After Service, by F. E. Rosenstiehl... 9-1, 14
Reduction Of Gear Failures, by S. D. Craine 9-2, 70
Relation Between Bearing Clearances & Bearing Life With Silicone Grease At 150 C., by G. Grant 9-2, 73
Scoring & Wear Of Spur Gears, by V. N. Borsoff & F. C. Younger 9-5, 259
Seals & Closures, by E. W. Fisher 9-4, 190
Significance Of Grease Testing, The, by A. E. Baker, E. G. Jackson & E. R. Booser 9-5, 249
Solid Lubricants, by W. E. Campbell 9-4, 195
Units Of Viscosity And Their Conversion, by D. D. Fuller & P. L. Tea, Jr. 9-6

Anderson, W. J., & E. F. Macks: Cooling & Lubrication Of High Speed Cylindrical Roller Bearings 9-5, 263
Baker, A. E., & E. G. Jackson E. R. Booser: The Significance Of Grease Testing 9-5, 249
Bisson, E. E.: The Influence Of Solid Surface Films On The Friction & Surface Damage Of Steel At High Sliding Velocities 9-2, 75
Bisson, E. E. (See: Johnson-Swikert-Bisson) 9-3, 144
Blok, H., & J. J. vanRossum: The Foil Bearing—A New Departure In Hydrodynamic Lubrication 9-6
Bloodgood, D. E.: Contamination Of Surface Waters By Waste Oils 9-2, 81
Booser, E. R., & D. F. Wilcock: Minimum Oil Requirements Of Ball Bearings 9-3, 140
Booser, E. R. (See: Baker-Jackson-Booser) 9-5, 249
Borsoff, V. N., & F. C. Younger: Scoring & Wear Of Spur Gears 9-5, 259
Bowers, R. C., & W. C. Clinton, W. A. Zisman: Frictional Behavior Of Polyethylene, Polytetrafluoroethylene & Halogenated Derivatives 9-4, 204
Boyd, J.: Mathematical Symbols For Lubrication Problems 9-4, 209
Burgess, P. B.: Mechanisms Of Sleeve Bearing Failure 9-6
Campbell, W. E.: Solid Lubricants 9-4, 195
Clinton, W. C. (See: Bowers-Clinton-Zisman) 9-4, 204
Cobb, L. D.: Effects Of Modern Design Trends On Ball Bearing Research 9-2, 78
Collins, L. J.: Lubrication Requirements Of Gears As Seen By A Gear Engineer 9-5, 246
Craine, S. D.: Reduction Of Gear Failures 9-2, 70
DeHart, A. O. (See: Roach-DeHart) 9-6
Feng, I-Ming, & B. C. Rightmire: The Mechanism Of Fretting 9-3, 134
Finkelmann, J. L.: Lubricating Greases 9-3, 127
Fisher, E. W.: Seals & Closures 9-4, 190
Fuller, D. D.: Air Bearings—Low Friction 9-6
Fuller, D. D., & P. L. Tea, Jr.: Units Of Viscosity And Their Conversion 9-6
Grant, G.: Relation Between Bearing Clearances & Bearing Life With Silicone Grease At 150 C 9-2, 73
Hibbert, L. J., & R. F. McKibben: The Evaluation Of Lubricants For Use In Computing Machines 9-1, 16
Jackson, E. G. (See: Baker-Jackson-Booser) 9-5, 249
Johnson, R. L., & M. A. Swikert, E. E. Bisson: The Lubrication Characteristics Of Synthetic Lubricants At High Sliding Velocities 9-3, 144
Lauterbach, W. E., & E. A. Ratzel: The Critical Rake Angle Method Of Evaluating Cutting Fluids 9-6
Macks, E. F.: The Fatigue Spin Rig—A New Apparatus For Rapidly Evaluating Materials & Lubricants For Rolling Contact 9-5, 254
Macks, E. F. (See: Anderson-Macks) 9-5, 263
McHugh, A.: Industrial Equipment User's Viewpoint (Progress Report: JIC Hydraulic Standards, Part III) 9-1, 26
McKibben, R. F. (See: Hibbert-McKibben) 9-1, 16
Morrow, A. S.: Cleaning Lubrication Systems 9-1, 10
Ratzel, E. A. (See: Lauterbach-Ratzel) 9-6
Rightmire, B. G. (See: Feng-Rightmire) 9-3, 134
Roach, A. E., & A. O. DeHart: Electrographic Spot Testing Of Bearing Surfaces 9-6
Robinson, J.: Hydraulic Equipment Builder's Viewpoint (Progress Report: JIC Hydraulic Standards, Part I) 9-1, 22
Rosenstiehl, F. E.: Recommended Practices For The Cleaning Of Turbine Lubricating Systems After Service 9-1, 14
Ryder, E. A.: The Development Of Significant Bench Tests For Aircraft Turbine Lubricants 9-4, 201
Stokely, J. M.: A New Performance Test For Cutting Fluids 9-3, 137
Swikert, M. A. (See: Johnson-Swikert-Bisson) 9-3, 144
Tea, P. L. Jr. (See: Fuller-Tea) 9-6
Tech, K. O.: Machine Tool Builder's Viewpoint (Progress Report: JIC Hydraulic Standards, Part II) 9-1, 24
vanRossum, J. J. (See: Blok-vanRossum) 9-6
West, A. C.: Friction & Boundary Lubrication 9-4, 211
Wilcock, D. F. (See: Booser-Wilcock) 9-3, 140
Winkler, H. W.: Open Gear Lubrication 9-6
Wojtowicz, W. J.: Evaluation Of Drawing Lubricants .. 9-1, 19
Younger, F. C. (See: Borsoff-Younger) 9-5, 259
Zisman, W. A. (See: Bowers-Clinton-Zisman) 9-4, 204

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(Section News, Continued from 301)

The program for the Boston Section monthly meetings for '54 includes: Feb. 8, Lubricating Greases, by T. G. Roehner; Mar. 15, Developments In Gears & Gear Lubricants, by D. W. Dudley; Apr. 26, Paper Mill Lubrication, by C. L. Pope; and May 17, Past Chairmen's Night. (Submitted by A. S. McNeilly, Sec'y.)

CLEVELAND: September meeting —Annual Fall golf party and clambake. (Submitted by R. H. Josephson, Sec'y.)

KINGSPORT: October meeting — R. Mensing, Socony Vacuum Oil Co., presented papers entitled Lubrication Of Gears, and The Recent Improvements In Additives. (Submitted by J. E. Fleenor, Sec'y-Treas.)

MILWAUKEE: September meeting — W. H. Millett, Carbide & Chemicals Co., presented a paper entitled Non-Flammable Hydraulic Fluids.

November meeting — Joint meeting with ESM, with Major General S. D. Sturgis, Jr., C.E., speaking on The Corps Of Engineers, The St. Lawrence Seaway And The Great Lakes System. (Submitted by R. W. Schroeder, Sec'y.)

NORTHERN CALIFORNIA: October meeting — R. D. Kelly, United Air Lines, presented a paper entitled Turbine-Powered Commercial Transport Aircraft, abstracted as follows:

"Commercial jet transport service will cut present flight time approximately in half. Jet transport planes to be successful must be approximately twice the weight of the current DC-6's. The cruising speed must be 530 miles per hour or better. Eighty or more first-class passengers (or 120 tourist passengers) must be accommodated plus normal baggage. The cost per airplane will be very high. The projected flight time, San Francisco-New York—is 5 hours, non-stop. The turboprop engine which has been much discussed will not be available as soon as the full jet engine so U. S. manufacturers will see the need for going directly to the jet airplane or being outclassed by aircraft of foreign manufacture. It is anticipated the jet engine will be ready for commercial application within the next 5 to 6 years."

November meeting — W. E. Campbell (ASLE President), Bell Telephone Laboratories, presented a paper entitled The Present Status Of Fretting Wear, describing the causes and methods of preventing fretting corrosion. (Submitted by R. H. Decker, Sec'y-Treas.)

PITTSBURGH: September meeting — J. P. Critchlow, Gulf Oil Co., presented a paper on the subject of Extreme Pressure Lubricants. (Submitted by L. A. Tachoir, Sec'y-Treas.)

SAGINAW VALLEY: September meeting — A "Stump the Experts" quiz program, with P. Uhl, Detroit Diesel Engine Div.; H. Schultz, Buick Motor Div.; S. Kimball, A. C. Spark Plug Div.; and J. Edmands, Bay City Shovels, as Panel Members. (Submitted by N. M. Pagels, Sec'y.)

SYRACUSE: September meeting — Annual election of officers (See ASLE Directory).

October meeting — C. L. Pope, Eastman Kodak Co., presented a paper entitled Simplification Of Industrial Oils Based On A Uniform Viscosity System. (Submitted by E. J. Naughton, Sec'y.)

TWIN CITIES: October meeting — V. A. Baxter, Western Oil & Fuel Co., presented a paper on the subject Evolution Of Automotive Lubrication. (Submitted by C. D. Johnson, Sec'y.)

(Lube In The News, from 312)

ciency. Of a water-base "snuff-type" material, it has shown the lubricating ability of high grade petroleum hydraulic oils, will not freeze, and is easily pumpable at working temperatures down to 0° F. The viscosity index of the liquid is 150, indicating resistance to viscosity changes at varying temperatures; laboratory and field tests show it can be used efficiently at 1,000 psi pump pressure, with film strength tests indicating further that it will carry 2½ times the load of conventional hydraulic oil of similar viscosity. For further information, write: E. F. Houghton & Co. (LE9/6), 303 W. Lehigh Ave., Phila. 33, Pa.

LUBRI-MIST No. 1 & No. 2: A new idea in an aerosol type bomb for spraying a fine mist of submicron size particles of molybdenum disulfide over and into friction surfaces has been announced. Available in two types, Lubri-Mist No. 1 has a volatile carrier giving dry lubrication, while Lubri-Mist No. 2, with a synthetic oil carrier offers an oily surface. Packaged in 12 oz. and 6 oz. sizes. For further information, write: Lubri-Mist Co., Inc. (LE9/6), Waukesha, Wisc.

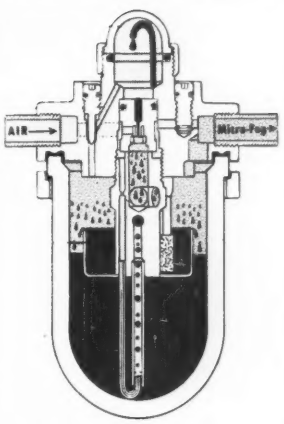
BARCOTE NO. 600, a new leaded petroleum compound developed for the protection of metal surfaces against corrosion, is recommended for four basic types of applications: (1) Corrosion protection of structural steel and sheet metal, (2) Protection of rails, and rail joints, (3) Lubrication of wire rope, and (4) Protection of metal parts in storage. A solvent, cut back, leaded compound, it provides coverage with a thin film which sets to a semi-hard coating of pure lubricant—with adhesion and penetration of all metals. Since the film is semi-hard and rubber-like in nature, it expands and contracts without flaking, cracking, pulling away, blistering or failing; it will flow at 0° F., does not emulsify with water and has penetrating action sufficient to carry it behind scale and

now Norgren micro-fog

FOR MULTIPLE-BEARING LUBRICATION

•

LUBRICATE UP TO 40 BEARINGS WITH ONE MICRO-FOG LUBRICATOR



Now, the advantages of Micro-Fog Lubricators have been extended to applications on bearings, gear boxes and small air-operated devices. It produces an extremely fine and uniform air-borne Micro-Fog at low air flow; transmits it over greater distances than previously possible; distributes it evenly thru as many as 40 outlets; provides exact control and uniform rate of oil feed.

WRITE FOR NEW CATALOG SHEET NO. 485

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through rust; it does not evaporate in storage, is soluble in petroleum solvents, and may be filtered through a .005 inch mesh unit. Write for Bulletin No. 61, The Brooks Oil Co. (LE9/6), 934 Ridge Ave., Pittsburgh 12, Pa.

AIR-PRIMED PORTABLE LUBRICATOR: Aro-Pak, a completely new air-primed portable lubricator, consists of a cylindrical tank holding 5 lbs. of grease, a handy carry strap, and hose and nozzle that enables the user to lubricate fittings in hard-to-reach locations with simple one-hand operation even in extreme cold weather. A hand pump primes the unit with air pressure in a minute, and one priming keeps 2½ lbs. of grease under pressure; no compressor is needed. Only 15 lbs. in weight when full, it features visual grease level indicator, volume control nozzle, full swiveling, with pressure booster feature. A companion unit, Aro-Fil gun filler, enables the user to quickly and easily fill the Aro-Pak (although it can be filled by hand) or any hand gun. For further details, write: Aro Equipment Co. (LE9/6), Bryan, Ohio.

Book Reviews

LEO UBBELOHDE, SEIN WIRKEN
by his pupils, colleagues, and friends. G. Braun, Karlsruhe, 1951, 164 pages, 21 illustrations, DM 12.

Among the technical participants of the second World Petroleum Congress in Paris, 1937, one met at many sessions and in the halls an imposing figure more mindful of the ancien regime ambassador than of the scientist. His discussion remarks were pointed and his speeches testified to an unusual perspective and breadth of vision. Such were the first impressions that Leo Ubbelohde left with the writer.

Professor Ubbelohde's contributions to applied science and especially to the field of lubrication have been manifold. The connection of his name with a variety of measuring devices and with standardization in our industry bears eloquent testimony to his pioneering activities, since reliable measurements and well defined units are the starting points of all real progress in technology. His demonstration, in a series of brilliant papers between 1905 and 1913, of the need to use absolute rather than the conventional viscosities of the petroleum industry in journal bearing calculations and of the futility of much of the "oil-testing" then going on, will forever stand as classical contribution to lubrication engineering literature.

In its emphasis on the civic activities of Professor Ubbelohde as organizer of philanthropic enterprises and as technical expert before the bar, this little "Festschrift" recognizes implicitly that public recognition of technical men is predicated upon their interest in their fellow men.

The booklet contains—in the form of 24 separate and apparently unedited contributions—the raw material for a biography rather than a coherent biography, and was assembled on the occasion of Professor Ubbelohde's 75th birthday.

A. Bondi

MACHINE TOOLS AND THEIR LUBRICATION

by Shell Oil Co., Publishers, 50 W. 50th St., New York 20, N. Y., or 100 Bush St., San Francisco, Calif., 1953, price: no charge.

An interesting history of the development of machine tools, a simple explanation of their mechanical aspects, and an analysis of the role of lubricants in their maintenance and operation are contained in MACHINE TOOLS AND THEIR LUBRICATION. The second number in the Volume II series of the Panorama of Lubrication booklets published by Shell, and written to be of interest both to readers unfamiliar with machine tools and to experienced machinists, it is not a manual on machine tool lubrication; instead, it is a comprehensive discussion of the fundamental factors found in the construction, operation, and maintenance of modern machine tools.

Containing many photographs and drawings in color to depict graphically the functions of the various components of machine tools and their lubricants, the booklet begins with an account of the development of machine tools, then shows how power is controlled and force is directed to shape metal by cutting and chipping, analyzes the factors that contribute to friction and wear, and describes the roles of lubricants. Specific classes of machine tools are described: lathes, milling machines, grinders, drills, broaches and tapping machines, planers, shapers and slotters, and contour cutting machines. Hydraulically actuated devices for operating and controlling certain actions of machine tools, which have become increasingly important in recent years, are discussed separately. The booklet concludes with a section on the various types of lubricants and their application.

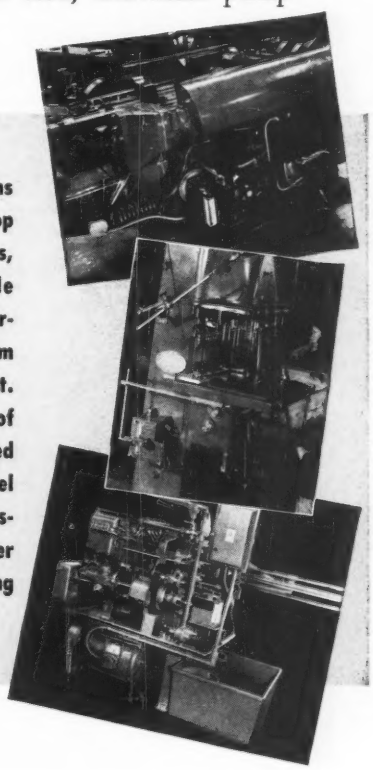
Patent Abstracts

Prepared by ANN BURCHICK from OFFICIAL GAZETTE, Vol. 673, No. 4; Vol. 674, Nos. 1, 2, 3, 4, 5; Vol. 675, Nos. 1,2. Printed copies of patents are available from the Patent Office at twenty-five cents each. Address the Commissioner of Patents, Washington, D. C. for copies and for general information concerning patents.

PREPARATION OF LUBRICATING OIL, Patent #2,650,188

Now PULSOLATOR
is made and sold
by Manzel

Manzel has added the world-famed *Pulsolator* to its established line of Force Feed Lubricators and Chemical Feeders. Thus, this 55 year old organization now offers low pressure, single pump lubrication for applications where the unlimited pressure of Manzel force feed, individual pump systems is not required.



Here are three typical applications showing *Pulsolator* automatic, loop systems for lubricating machine tools, printing presses and comparable equipment. As many as 1,000 bearings can be lubricated by one system from a loop line of up to 300 feet. Capacities, timing, and quantity of lubricant delivered can be adapted to individual requirements. Manzel engineers will be glad to plan a system to meet your exact needs either on new machines you are planning or on existing equipment.

Manzel

DIVISION OF FRONTIER INDUSTRIES
273 BABCOCK STREET, BUFFALO 10, NEW YORK

by G. E. Reese & J. L. Larkin, assignors to Sun Oil Co.

In a process for preparing lubricating oil from naphthenic base crude petroleum wherein hydrocarbons boiling below the lubricating oil range are removed as distillate in a primary distillation step and lubricating oil is removed as distillate in a subsequent vacuum distillation step, the steps for producing lubricating oil having improved bloom and color stability characteristics which consist of reacting the charge to one of said distillation steps with ammonia in the presence of caustic soda, said ammonia and caustic soda having been added in amounts of at least 1.2 lbs. NaOH and 0.1 lb. NH_3, respectively, per bbl. of mazout resulting from said first distillation step.

OIL-SOLUBLE PETROLEUM SULFONATES, Patent #2,650,198

by W. Kronig, H. Seeles, & H. Burmeister, assignors to Shell Development Co.

A process for the preparation of an oil solution of ammonium petroleum sulfonates which comprises: sulfonating a mineral oil fraction; separating an oil solution of petroleum sulfonic acids from the resulting sulfonation admixture; neutralizing the oil-soluble petroleum sulfonic acids in said oil solution with an aqueous alcoholic solution of a basic-acting alkali metal compound; concentrating the resulting oil-soluble alkali metal petroleum sulfonates by removal of the alcohol from admixture therewith; dissolving the concentrated oil-soluble alkali metal petroleum sulfonates in a highly refined mineral oil having a viscosity of between about 50 and about 180 SSU/100 F.; converting said petroleum sulfonates in the resulting oil solution to their corresponding petroleum sulfonic acids by treating with a mineral acid; adding thereto a minor amount sufficient to prevent an increase in viscosity of said oil solution during a subsequent neutralization step of metaphosphoric acid and neutralizing the resulting admixture of petroleum sulfonic acids and meta-phosphoric acid in oil with ammonia.

LITHIUM HYDROXY STEARATE GREASE COMPOSITIONS, Patent #2,651,616

by J. B. Matthews, D. Evans, J. F. Hutton, & J. O. Cliffe, assignors to Shell Development Co.

A method of manufacturing a lubricating grease which comprises heating an oleaginous vehicle mixed with a grease forming amount of alkali metal aliphatic monocarboxylic acid soaps containing at least 35% lithium hydroxy fatty acid soaps until a homogeneous composition is formed, cooling said composition to a temperature between about 110 C. and about 170 C. at a rate between 1 C. and 3 C. per minute, isothermally gelling the composition between said temperatures and subsequently cooling the grease.

GREASE COMPOSITIONS, Patent #2,652,361

by H. A. Woods & L. C. Bollinger, assignors to Shell Development Co.

Gasoline-resistant grease comprising between about 5% and about 25% by weight of an inorganic colloidal gel, a water-soluble polyoxyalkylene fluid and a partial ester of a polyhydric alcohol having from 2 to 10 carbon atoms with a higher fatty acid, the proportion of polyoxyalkylene fluid varying between about 2 and about 4 parts by weight for each 5 parts of weight of said ester.

GREASE COMPOSITION, Patent #2,652,362

by H. A. Woods & R. C. Jones, assignors to Shell Development Co

A grease composition comprising a major amount of a lubricating oil having incorporated therein an amount sufficient to form a grease of a gelling agent and 0.01 to 5% each of an aromatic naphthyl amine and the reaction product of phosphorus pentasulfide and a dicyclic terpene.

GREASE COMPOSITIONS, Patent #2,652,363

by H. A. Woods & L. C. Bollinger, assignors to Shell Development Co.

A gasoline-resistant grease comprising a gelling amount of hydroxyalkylamine soap of a higher fatty acid, 20-50% by weight of a water soluble polyoxyalkylene fluid and 30-60% by weight of a partial ester of a polyhydric alcohol having less than six carbon atoms with a higher fatty acid.

HIGH TEMPERATURE GREASE COMPOSITIONS, Patent #2,652,364

by H. A. Woods & L. C. Bollinger, assignors to Shell Development Co.

A lubricating grease composition comprising as the lubricating base thereof a mixture of from 55% to about 95% by weight of a synthetic high boiling liquid polyhydrocarbylsiloxane having a viscosity within the lubricating oil viscosity range and from about 5% to about 45% by weight of a mineral oil having a viscosity of between about 1250 and about 11,000 SUS at 100 F., said mineral oil containing less than about 15% by weight of aromatic hydrocarbons, the lubricating base being thickened to a grease consistency by a sodium soap of

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600 FIFTH AVENUE, NEW YORK 20, N. Y.

a carboxylic acid having at least 20 carbon atoms per molecule, said grease containing a minor proportion of an alkali metal salt of an organic carboxylic acid containing an aromatic ring.

MANUFACTURE OF GREASE COMPOSITIONS— Patent #2,652,365
by R. J. Moore & J. N. Wilson, assignors to Shell Development Co.
The method of making a wide temperature grease composition comprising admixing an oil having a viscosity above 500 at 100 F. SUS with a grease forming gelling agent in an amount so that the gelling agent comprises from 10% to about 50% of the mixture, heating until a homogeneous non-crystalline mass has formed, cooling said grease concentrate to a temperature below 100 C., and admixing into said grease concentrate at this temperature a light oil having a viscosity below 300 at 100 F. SUS until the content of the gelling agent based on the total composition ranges from about 5% to about 15% by weight.

METHOD OF PREPARING LUBRICATING GREASE COMPOSITIONS, Patent #2, 652, 366
by R. C. Jones & R. J. Wall, assignors to Shell Development Co.
A process for the preparation of a lubricating grease which comprises heating a mixture of a lubricating oil and a grease forming amount of a gelling agent therefor to about solution temperature T_1, quenching the heated mixture in a period of time less than about one minute to a lower temperature T_2 between about 25 F. and 55 F. lower than said solution temperature T_1 substantially all of the quenching being conducted before any substantial shearing of the mixture, and thereafter shearing said mixture at temperature T_2 to form a grease, the amount of shearing performed upon said grease being at least 4000 ft. lbs. per pound of finished grease.

LUBRICATING COMPOSITION, Patent #2, 652,367
by D. E. Adelson, assignor to Shell Development Co.
A lubricant comprising a major amount of mineral oil and a minor amount, sufficient to stabilize said lubricant against deterioration, of a reaction product obtained by reacting an organic carbonyl compound selected from the group consisting of ketones and aldehydes with an alkylene polyamine in the mole ratio of 2 to 6:1 to 3, respectively, and at a temperature of from 50 to 250 C. until water formation ceases and treating the resulting reaction product with an inorganic carbon-free sulfur compound selected from the group consisting of phosphorus sulfide, sulfur halide, and sulfur in the mole ratio of from 1:1 to 1:8, respectively, at a temperature ranging from below zero degree to about 175 C. and for a period of from 3 to 24 hours.

LUBRICATING OIL COMPOSITION, Patent #2,652,368
by D. S. Melstrom & F. J. Watson, assignors to Shell Development Co.
A lubricant comprising a hydrocarbon lubricating oil base and in admixture therewith a minor amount sufficient to improve the viscosity index of the oil of a copolymer of cracked wax olefins and sulfur dioxide having a molecular weight between about 5000 and 100,000.

ALUMINUM-CARBON BLACK THICKENED GREASE COMPOSITIONS, Patent

TWO NEW HOUGHTON FORTIFIED LUBRICANTS

Get full details*

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Highly adhesive open gear and cable lubricant

This new lubricant is made in three grades (light, medium, heavy) for heavy-duty service for open gears, cables, presses, shovels, hoists, shears, cranes and other applications where conditions do not permit enclosure. It can be applied by spray, brush, swab, or dip, without preheating. Resists moisture. Has high film strength, lubricity and oiliness. And as its name implies—it is tenacious—it hangs on!

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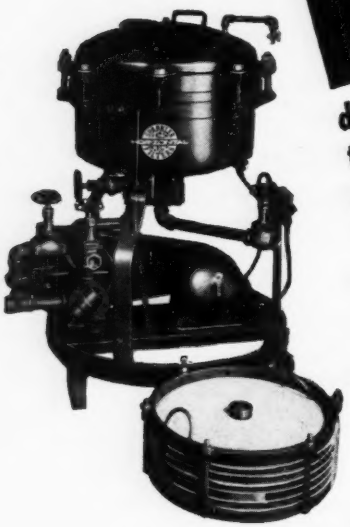

The VR filter is designed for filtering hydraulic oil, quenching oils, transformer oil, solvents and other industrial liquids.

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★ Filtering hydraulic oil extends the life of the oil. Drain and leakage oil may be reclaimed. One large user of hydraulic machinery saved $90,000.00 in hydraulic oil alone in one year by filtering oil with Sparkler Filters.

★ Filtering hydraulic oil eliminates sticking and clogging of valves and reduces down time and maintenance cost. A prominent authority on hydraulic machinery says that 70% of servicing and repairs is due to the improper condition of hydraulic oil.

★ Filtering coolant fluid removes all fine metal particles and grit from grinding wheels that is pumped back to nozzles unless a filter is employed in cleaning up the return coolant.

★ Clean filtered coolant prevents scratching and flat spots on work piece and increases the life of grinding wheels and cutting tools. Reduces the frequency of dressing grinding wheels.

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#2,653,131
by Rosemary O'Halloran, assignor to Standard Oil Development Co.
An improved process for the formation of lubricating grease compositions containing combined therein carbon black which comprises the steps of admixing from 1.5% to 10.0% by weight of an aluminum soap of high molecular weight substantially saturated fatty acid in a mineral oil, heating said mixture to completely disperse said soap in said oil, cooling the dispersion below the transition temperature of said aluminum soap, blending with said cooled soap-oil solution from 3% to 30% by weight of an amorphous carbon black, and working the resulting blend until the desired consistency is obtained.

OXO-BOTTOMS BASE LUBRICATING GREASE—Patent #2,653,132
by A. J. Morway & P. V. Smith, Jr., assignors to Standard Oil Development Co.
A new and improved grease composition which comprises a synthetic oil thickened to a grease consistency with from about 5.0% to 20.0% by weight of the lithium soap of a high molecular weight substantially saturated fatty acid, said synthetic oil being the residue of distillation at a temperature of about 210 C. of the mixture of products obtained by subjecting a mono-olefin to the action of carbon monoxide and hydrogen in the presence of a cobalt catalyst at a temperature of about 300 F. to 350 F. and under a pressure of about 3000 pounds per square inch which has been hydrogenated to a predominately primary alcohol mixture containing one more carbon atom than the mono olefin.

COPOLYMERS AND LUBRICANTS CONTAINING THE SAME, Patent #2,653,-133
by W. E. Catlin, assignor to E. I. duPont de Nemours & Co.
A lubricating oil containing from 0.1% to 10% by weight thereof of an oil-soluble copolymer of a nitrile from the group consisting of acrylonitrile and methacrylonitrile, and an alkyl ester in which the alkyl group contains from 10 to 18 carbon atoms, inclusive, of an unsaturated acid from the group consisting of acrylic and methacrylic acids, said nitrile amounting to 2% to 20% by weight of said copolymer.

SURFACE ACTIVE COMPOUNDS, Patent #2,653,135
by W. B. Hughes & E. B. Fisher, assigners to Cities Service Research & Development Co.
The process of resolving emulsions which includes mixing with a petroleum water-in-oil emulsion a resolving agent consisting of a product prepared by mixing together from one to three mols of an aliphatic aldehyde having more than one carbon atom and one mol of a mixture of a polyethylene amine and an alkyl amine having more than four carbon atoms, heating the aldehyde-amine mixture for a period of from about one half to one hour at a temperature slightly below the boiling point of the mixture, and neutralizing the resultant product to a methyl orange end point with propylated naphthalene sulfonic acid, the agent being mixed in an amount small but sufficient to cause substantial resolution of the emulsion, allowing the treated emulsion to settle into an oil phase and a water

phase, and separating the oil from the water.

SOLUBLE OILS COMPRISING NEUTRALIZED OXIDIZED PETROLEUM OILS, Patent #2,653,909
by D. Frazier, assignor to The Standard Oil Co.
A machining fluid comprising an emulsion of water with an oxidized, neutralized oil prepared by oxidizing a refined lubricating oil solvent extracted to have a viscosity ranging from about 75 to 600 SUS at 100 F., an ASTM aniline point of at least 105 C. and then neutralizing said oxidized oil with a strong base dissolved in a mutual solvent for the base and the soap resulting from said neutralization, said oil containing at least about 0.1% by weight of said solvent.

EXTREME PRESSURE LUBRICANTS, Patent #2,653,910
by R. S. Airs & V. W. David, assignors to Shell Development Co.
An oleaginous lubricating composition comprising a major amount of a lubricating oil base having incorporated therein a minor amount, sufficient to provide the composition with extreme pressure properties, of an organic trichalcogenone.

DEWAXING MINERAL OIL, Patent #2,654,693
by C. F. Sacra, assignor to Shell Development Co.
The process of dewaxing a substantially asphalt-free wax-containing mineral lubricating oil distillate which comprises: cooling a liquid admixture of said mineral oil distillate and a dewaxing solvent consisting essentially of methyl ethyl ketone and propane, the solvent to oil volume ratio being from about 4:1 to 6:1 and the ketone to propane volume ratio being from about 3:2 to 4:1, to precipitate solid wax from the oil, separating the precipitated wax.

TREATMENT OF LUBRICATING OIL, Patent #2,654,696
by W. N. La Porte, assignor to Sun Oil Co.
Process for improving the color of distillate lubricating oil without substantial hydrogenation of unsaturated hydrocarbons in said oil which comprises: passing said oil downwardly at a temperature within the approximate range from 450 F. to 575 F. through a bed of 4-20 mesh hydrogen-treating calalyst in the presence of hydrogen at a pressure within the range from 10 to 35 atmospheres and at a space rate within the range from 1 to 5 volumes of oil per volume of catalyst per hour and at a flow rate within the range from 10 to 160 cubic feet of oil per square foot of catalyst bed cross-section per hour, thereby to maintain a relatively thick liquid film of oil on the catalyst: and recovering from said bed a lubricating oil having refractive index within 0.001 of the refractive index of the charge oil, and having color substantially improved over that of the charge oil.

POLYSILOXANE-ALUMINUM SOAP GREASES, Patent #2,654,710
by B. W. Hotten, assignor to California Research Corp.
A grease composition comprising a major proportion of a polysiloxane base oil and a complex basic aluminum soap in an amount sufficient to thicken the polysiloxane base oil to the consistency of a grease, said complex basic aluminum soap having at least two unlike organo-anions, one organo-anion derived from an organic acid, the aluminum di-soap of which acid is characterized by oil solubility of at least 5% at 400 F., and another organo-anion derived from an organic acid, the aluminum di-soap of which acid is characterized by an oil solubility of less than 1% at 400 F.

MONOCYCLIC TERPENE-SULFUR-PHOSPHORUS SULFIDE REACTION PRODUCT AND LUBRICATING OIL CONTAINING THE SAME, Patent #2,654,711
by A. D. Kirshenbaum & H. W. Rudel, assignors to Standard Oil Development Co.
A mineral lubricating oil composition containing 0.05 to 50% by weight of a product obtained by simultaneously reacting one molecular proportion of a monocyclic terpene with about 1.5 to about 2 atomic proportions of sulfur and with about 0.01 to about 0.25 molecular proportions of a sulfide of phosphorus at a temperature of at least 120 C. and up to a temperature of about 200 C.

Board Actions

At the ASLE Executive Committee Meeting, June 17, 1953, it was agreed the Actions of the Board of Directors be published in the Society's journal. The Actions of general interest for the calendar year of 1953 are herewith recorded as directed. W. H. Fowler, Jr., Sec'y-Treas.

ACT, 1-24-53: The Board of Directors moved that the Finance Committee, in presenting future proposed budgets, show the breakdown of the previous year's budget as well as the income and disbursements against that budget.

ACT, 1-24-53: Motion was made and passed that the Executive Committee recommend to the Board of Directors that ASLE continue to rotate the meeting place for the Annual Meeting among various Section headquarters for the present.

ACT, 1-24-53: W. E. Campbell moved that the membership rolls of the Society shall not be used for solicitation except with the approval of the Executive Committee.

RESOLUTION, 1-24-53: Resolved, that, to provide needed continuity, the Program Committee shall consist of six members; three of whom are appointees by the President. Of these three members, the one with the longest tenure on the Committee be the Chairman; the one with the next longest tenure, be Vice-Chairman and Chairman-elect, and the junior member be one appointed by the President each year, succeeding to the Vice-Chairmanship at the time of the appointment of the next junior member. The remainder of the Committee shall consist of the Chairman of the General Technical Committee, the Chairman of the Editorial Committee and the most recently retired Chairman of the Program Committee.

RESOLUTION, 1-24-53: Resolved, that,

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members of the American Society of Lubrication Engineers recalled into the armed services, have their membership dues waived for the duration of such service.

RESOLUTION, 4-15-53: Resolved, that the resolution of the Executive Committee adopted July 19, 1952, allocating the regional territories of the respective regional vice-presidents, be rescinded herewith, and, that the territories of the respective regional vice-presidents be:

Eastern: New York, Pennsylvania, West Virginia, North Carolina, Georgia, Florida and all states East thereof.

Mid-Western: North Dakota, South Dakota, Kansas, Nebraska, Oklahoma, Texas, and all states between there and the above eastern boundary.

Western: All the remaining states in the United States and the Canadian Provinces of British Columbia and Alberta.

Canadian: All the remaining provinces of Canada.

This reallocation is based on the natural geographical boundary imposed by the Rocky Mountains. It also looks to the time when it may be desirable to create a new Southern or Southwestern region when new sections are developed there.

ACT, 4-15-53: P. F. Chappell moved that the symbols on bearing problems be adopted as standard for the Society. D. F. Hollingsworth recommended that a list of these symbols be submitted to A.S.A.

ACT, 6-18-53: P. F. Chappell moved that a Second National ASLE Symposium on the subject of Synthetic Lubricants be held in the fall of 1954.

ACT, 6-18-53: It was moved by W. C. Kesler, that the 1955 Annual Meeting and Exhibit be held at the Hotel Sherman in Chicago, April 13, 14 and 15.

Current Literature

THE SELECTION OF LUBRICANTS FOR INDUSTRIAL PURPOSES
by H. E. Priston, Chemistry & Industry, No. 31, Aug. 1, 1953, pp. 809-813.
The degree of refinement to which an oil is subjected is governed by the purpose for which it is to be used, and whereas a highly refined mineral oil, possibly containing an oxidation inhibitor, is necessary for bearings fed by a circulating system where the oil is used again and again and any oxidation or thickening of the oil in service is undesirable, the same degree of refinement would not be necessary in the case of oil fed to bearings on the "total loss" principle, where oxidation of the oil is of lesser importance. Special characteristics needed for steam-engine lubrication, steam turbine lubrication, diesel and petrol engine lubrication, compressor lubrication, general bearing lubrication, gear lubrication, and lubrication of ball and roller bearings are taken up.

THE KINETIC STUDY OF DETERIORATION IN USE OF INTERNAL COMBUSTION ENGINE CRANKCASE OILS
by J. Hughes & J. B. Matthews, Journal of the Institute of Petroleum, Vol. 39, No. 355, July, 1953, pp. 463-486.
Mathematical equations are derived which describe the kinetics of the deterioration of internal combustion engine crankcase oils in its various aspects, such as the accumulation of oil-insolubles and soluble oil oxidation products and the depletion of additives. By the application of these equations it is shown how a closer understanding can be obtained of the mechanisms of oil deterioration. When applied to additive depletion the kinetic approach is shown to be useful in throwing light on the causes of additive depletion. In addition, the kinetic approach makes possible the calculation of the optimum additive concentrations required for specified engine operating conditions and of the maximum oil change periods.

CONTRIBUTION OF THE THEORY OF OIL WHIP
by H. Poritsky, Transactions of the ASME, Vol. 75, No. 6, Aug., 1953, pp. 1153-1161.
Oil whip of a rotor consists in a whipping or whirling motion of the rotor shaft, of frequency essentially equal to the critical frequency of the rotor; it occurs at rotor speeds, roughly exceeding double the critical speed. In the paper it is shown that an explanation of oil-whip phenomena, at least for small eccentricities, can be obtained from the equations of hydrodynamic forces and the dynamical equations of motion, provided that the hydrodynamic-force expressions be modified to delete from the oil forces the hitherto included contributions from the regions of negative pressure.

GLOSSARY OF TERMS USED IN PETROLEUM REFINING
by Anon, published by API Div. of Re-

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fining, Platt's Oilgram, Vol. 31, No. 165, Aug. 25, 1953, p. 2.

Book gives definition, pronunciation, and Gregg & Pitman shorthand forms for more than 2,000 colloquial and technical phrases. Hard cover editions may be obtained through Lacey Walker, Scretary, American Petroleum Institute, 50 W. 50th St., New York 20, N. Y., at $6.00 each.

THE CORRELATION BETWEEN VISCOSITY & PRESSURE AND THE EFFECT OF THIS PROPERTY ON THE LUBRICATION OF SLIDING SURFACES

by W. Kochanowsky, Kolloid Zeitschrift, Vol. 131, No. 2, May, 1953, pp. 74-83.

The author tries to refute the commonly accepted exponential law expressing the viscosity/pressure relationship. He claims that the assumption that the temperature in the interior of the lubricating layer is constant, fails to hold in the instance of high-load bearings; depending upon the material of the bearings and heat outlet the heat in bearings may become very high under high loads. The exponential law should therefore be replaced by another formula. A root law, for example, would yield values which approximate those obtained in the conventional manner for lower pressures, but would give much lower viscosity values for high pressures. A hydrodynamic theory can not explain the fact that with decreasing velocity friction reincreases after passing through a minimum. This event, due to mixed friction must be explained by considering both liquid friction and solid friction. Numerical examples illustrate the differences in practical results obtained by the two methods, and compare them with experimental data.

SPONTANEOUS IGNITION OF LUBRICATING OILS

by C. E. Frank, A. U. Blackham & D. E. Swarts, Industrial & Engineering Chemistry, Vol. 45, No. 8, Aug., 1953, pp. 1753-1759.

This paper summarizes a continuation of the study on spontaneous ignition phenomena previously reported with emphasis on various types of lubricating oils. To obtain significant results, it was necessary to employ spray injection rather than dropwise addition to the ignition chamber. Examination of lubricants and potential lubricants including parafin oils, polyethylenes, polyethers, esters of dibasic acids, polypropylenes, and polyisobutylenes has given spontaneous ignition temperatures below 300 C., for all except the polyisobutylenes. The resistance of polyisobutylene apparently is due to its high percentage of primary C-H bonds. Additional data is given on the influence of structure, additives, and metal surfaces on spontaneous ignition temperatures, and on the ignition behavior of selected two-component mixtures.

INTERFACIAL ACTIVITIES & PORPHYRIN CONTENTS OF PETROLEUM EXTRACTS

by H. N. Dunning & J. W. Moore, Industrial & Engineering Chemistry, Vol. 48, No. 8, Aug., 1953, pp. 1759-1765.

A California crude oil has been studied by solvent fractionation, supplemented by chromatographic procedures. The interfacial activities, film-forming tendencies, concentrations of metal-porphyrin complexes, and free porphyrin concentrations for the various extracts have been determined. The results show the presence of a considerable amount of the nickel-porphyrin complex and indicate smaller amounts of the vanadium-porphyrin complex. Correlations of interfacial activities and porphyrin contents show that the metallic porphyrin complexes identified are large contributors to the interfacial activity of petroleum.

RENOVATION OF USED OILS WITH CARBON & ACTIVATED ALUMINA

by A. E. Williams, Scientific Lubrication, Vol. 5, No. 9, Sept. 1953, pp. 19, 22-23.

Recovery of used lubricating oil is complicated in case of oils having additives. Regeneration removes the additives for all practical purposes. Centrifugal machines eliminate some of the water and most of the sludge, but traces of both these impurities may be present. In drying the oil under vacuum, any acids in the oil will tend to remain there in a concentrated form, so that vacuum drying is commonly applied to oils that are merely wet and otherwise good. Research work has shown conclusively that a suitable type of activated carbon is capable of taking up from used oil its entire water, acidity and sludge in one operation. Carbon treatment is described. Activated alumina possesses adsorptive properties for very many other substances than water. It also eliminates acid and sludge. The alumina may be reactivated by controlled burning away of the carbonaceous matter.

THE ROLE OF POROSITY IN FILTRATION—Numerical Methods For Constant Rate & Constant Pressure Filtration Based On Kozeny's Law

by F. M. Tiller, Chemical Engineering Progress, Vol. 49, No 9, Sept., 1953, pp. 467-479.

Based upon the Kozeny law relating the rate of flow to the porosity, a method was developed for determining (a) the pressure drop vs. the depth and the flow rate vs. the applied pressure in a fixed bed of solids, (b) the pressure vs. time relationship in constant rate filtration, and (c) the volume vs. time relationship in constant pressure filtration. Experimental porosity vs. pressure data are presented for such materials as kaolin, calcium carbonate, carbon black (suchar), diatomaceous earth (hyflo), asbestos, and mixtures of these materials.

MOLYBDENUM DISULFIDE AS A LUBRICANT

by Anon, Diesel Power, Vol. 31, No. 4., April 1953, pp. 90-93.

Molybdenum disulfide has been proven in service to be an effective lubricant under operating conditions where other lubricants have failed. Its main uses are: as an aid in the assemby and disassembly of close-fitting parts; as a lubricant in the hot and cold working and forming of metals; as a lubricant for parts which must function properly at high and low temperatures; as a non-dust-collecting lubricant; and, as a dielectric lubricant. It has good chemical and thermal stability, does not attack metals and has been used to retard corrosion. Lubricating properties are attributed to its laminar type crystalline structure.

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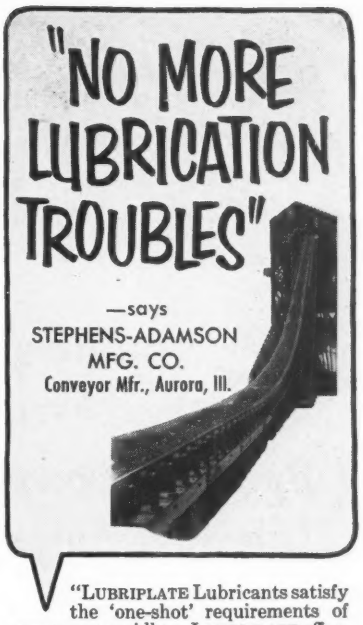

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7. **Eliminates product spoilage from dripping of excessive lubricant.**
8. **Reduces power requirements by eliminating friction—maintains power used consistent with work done.**
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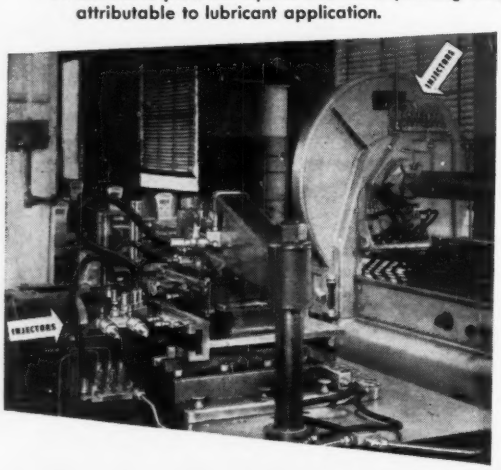

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by Anon, Chemical & Engineering News, Vol. 31, No. 16, April 20, 1953, p. 1662.

Polymetehylphenylssilxanes and phenylcyclopolysiloxanes have proved effective as antioxidants from 100 to 150 C. in grease gelled by sodium, lithium, calcium and aluminum, according to work underway at the Naval Research Laboratory's lubrication branch. The inhibitory effect appears to increase as oxidation progresses. NRL postulates this mechanism to explain the antioxidant activity and the fact that no inhibition occurs in the absence of metallic soap: polyorganosiloxanes are adsorbed on the soap particles, then liberate radicals which interrupt the reaction chain of auto-oxidation.

SOME EFFECTS OF SURFACE CURVATURE ON LAMINAR BOUNDARY-LAYER FLOW

by J. S. Murphy, Journal of the Aeronautical Sciences, Vol. 20, No. 5, May 1953, pp. 338-344.

The laminar flow of a viscous incompressible fluid over a two-dimensional curved surface is investigated for two cases, one in which the curvature is "large" and the other in which it is "moderate." The results indicate that for equal Reynolds Numbers, the stress on convex surfaces is less than the flat-plate value, while the stress on concave surfaces is greater than for a flat plate. The most important effect of surface curvature, for the cases considered, is the modification of the shape of the velocity profile near the "outer edge" of the boundary layer.

THIXOTROPY OF LUBRICATING GREASES

by B. W. Hotten & B. B. Farrington, A.S.T.M. Bulletin No. 189, April 1953, pp. 53-56.

A simple worker-penetrometer test has been developed for the measurement of thixotropy of lubricating greases. Shear softening and age stiffening are measured separately. Typical lithium, sodium, calcium, barium, and aluminum soap greases were measured. A wide variety in magnitude and in extent of reversibility of thixotropic properties was shown among this group of greases. Reproducibility of the test among the section members was good.

USE OF SYNTHETIC LUBRICANTS

by Anon, Petroleum Engineer, Vol. 25, No. 4, April 1953, pp. C-62-63.

Synthetic lubricating fluids are being used in compounding commercial lubricants. Two types of synthetic lubricating fluids can be considered. The first is the class, largely of hydrocarbon origin, which have been prepared as substitutes for natural mineral oils. The second consists of various fluids that have been developed to supplement natural products because one or more characteristics of the synthetics are superior to the corresponding characteristics of the natural products. Uses of polybutenes, polyalkylene glycols, esters, and silicon fluids are discussed.

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What's A Better Name For Oilers?

(Reprinted from FACTORY MANAGEMENT & MAINTENANCE, Nov. '53)

In February of last year we asked for suggestions for a better name for "oilers." So many people seemed dissatisfied with it, felt it didn't dignify the real responsibilities of the job.

Well, we received suggestions, and some surprises, too. We were told that other names actually in use are: machine lubricator, lubrication service man, machine service man, equipment service man. These last two titles were fostered by prominent members of the American Society of Lubrication Engineers. They applied them to upgraded machinists, millwrights, and machine repairmen.

One company reported it does not use the term "oiler" alone, but combines it with the man's other duties, such as "pump repairman and oiler." In the same plant men who lubricate motors and keep them clean are called "motor tenders."

Trying to be helpful, some readers suggested these new titles: cleanator, friction operator, servicemen, friction mechanic, machine tender. Said one plant: "We had difficulty getting people to take a job cleaning out coolant and sludge from machines and pits when we classified it as 'machine and sump cleaner.' Our employment manager suggested we change it to 'machine cleaner,' which we did, and have had no trouble since."

This sort of letter made FACTORY editors feel they were not running up a blind alley. But then another ASLE member said:

"If the man on the job has the requisite intelligence to do the job properly, he is intelligent enough to see through a stratagem of title that adds nothing to his stature or dignity. After all, while the job has progressed since we could turn a casual laborer loose with an oil can, a ball of waste, and a chew of tobacco, the term oiler is a good honest description of an honorable and dignified occupation.

"Calling the policeman on the corner a municipal traffic director does not change his appearance or function. Neither does calling an oiler anything else."

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84 E. Randolph St.
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Advertiser Index

Acheson Colloids Co. 285
Alemite Div., Stewart Warner Corp. 282
Apex Motor Fuel Co. 320
Brooks Oil Co., The 318
Burns Laboratories, Inc 319
Classified (2) 335
Climax Molybdenum Co. 281
Farval Corp., The ..... (Inside Back Cover)
Grafo Colloids Corp. 335
Hodson Corp., The ..... (Back Cover)
Honan-Crane Corp. 290
Houghton, E. F., & Co. 327
Ironsides Co. 284
Lincoln Engineering Co. 332
Lubriplate Div., Fiske Bros. Refining Co. ... 331
Madison-Kipp Corp. 287
Manzel Div. of Frontier Industries Inc. 325
Morgan Construction Co. 286
National Lead Co., Baroid Sales Div. 283
Norgren, C. A., Co. 323
Oil-Rite Corp. 320
Scientific Publications 329
Shell Oil Co. 288
Sinclair Refining Co. 326
Sparkler Mfg. Co. 328
Sun Oil Co. 291
Tide Water Assoc. Oil Co. 289
Trabon Engineering Corp. ... (Inside Front Cover)
Trico Fuse Mfg. Co. 319

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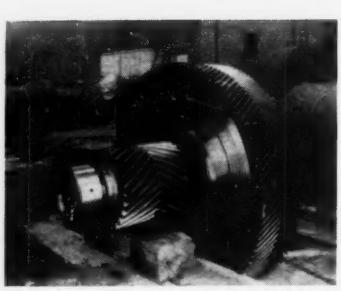

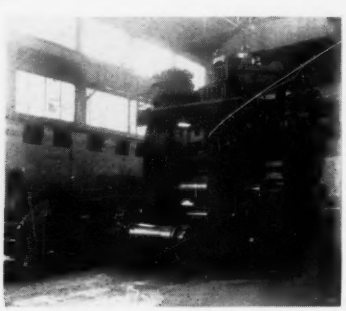

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